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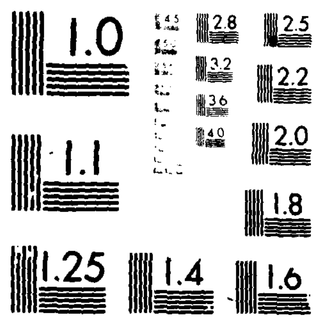

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DESIGN OPTIONS STUDY

Final Report

USAF Aeronautical Systems Division
Contract F33615-78-C-0114
February 29, 1980

Advanced Airplane Branch
of
The Boeing Military Airplane Company
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)
The Design Options Study considered a number of desired military features applied to a new commercial freighter and examined the commercial operating cost penalties and military life cycle costs. An I.O.C. of 1990 is projected for the new commercial freighter aircraft and the military design options, based upon a 1985 technology maturity date for the key technologies. The baseline aircraft incorporates graphite epoxy primary structure, active flight controls, advanced engines and aircraft systems.

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Following a preliminary investigation of many design features unique to military cargo aircraft, eleven design options were selected for detailed examination with regard to mission effectiveness and mission flexibility. The options selected were: quick-change floor panels, stabilizing struts, kneeling landing gear, air transportable mobile loader, onboard front ramp, side cargo door, swing tail cargo door, lowered military floor, cargo pod, passenger modules, and convertible airplane. The design options were evaluated by examination of their impact on two contingency scenarios: 1) early reinforcement of the NATO forces, and 2) movement of a mobile force into the Persian Gulf area as well as commercial costs. Three design option parameters, conversion time, payload, and utilization, were evaluated for each option and used to determine the CRAF fleet sizes required to augment a minimum organic military force. Mission analysis of fleet requirements for the two scenarios revealed NATO as being the more critical.

Several of the design options appear quite attractive from the point of view of commercial penalty and high military benefit. This is especially true for the quick change floor option utilizing the mobile loader. It appears that use of the dedicated commercial freighter uncompromised, but with selective military loading preprogrammed to optimize unit payloads, can provide a major portion of the airlift with only a minor increase in the organic fleet. One of the most pervasive influences in the study was the cost of the Enhanced CRAF provisions on the Design Options airplanes. Commercial pricing was used for both the baseline airplane and the provisions. However, because the CRAF provisions were developed and procured on a small unit buy relative to the baseline airplane the relative cost of the CRAF provisions are high, and significantly influence the results.

SUMMARY

The Design Options Study was an outgrowth of the Innovative Aircraft Design Studies (IADS) sponsored by the ASD/XRL which had as their objectives the identification of the most cost-effective means of providing additional U. S. airlift capability. Design features having military/commercial commonality were identified as one means of achieving the needed airlift. However, not all the military features desired were compatible with commercial air freighter requirements. The Design Options Study considered a number of desired military features applied to a new commercial freighter and examined the commercial operating cost penalties and military life cycle costs. An I.O.C. of 1990 is projected for the new commercial freighter aircraft and the military design options, based upon a 1985 technology maturity date for the key technologies. The baseline aircraft incorporates graphite/epoxy primary structure, active flight controls advanced engines and aircraft systems.

Following a preliminary investigation of many design features unique to military cargo aircraft, eleven design options were selected by the USAF Project Manager for detailed examination and evaluation with regard to mission effectiveness and mission flexibility. The options selected were: quick-change floor panels, stabilizing struts, kneeling landing gear, air transportable mobile loader, onboard front ramp, side cargo door, swing tail cargo door, lowered military floor, cargo pod, passenger modules, and convertible airplane. The design options were evaluated by examination of their impact on two contingency scenarios: (a) NATO and (b) the Middle East. Three design option parameters, conversion time, payload and utilization, were evaluated for each option and used to determine the CRAF fleet sizes required to augment a minimum organic military force. Mission analysis of fleet requirements for the two scenarios revealed NATO as being the more critical.

Several of the design options appear quite attractive from the point of view of commercial penalty and high military benefit. This is especially true for the quick change floor option utilizing the mobile loader. In fact, it appears that use of the dedicated commercial freighter uncompromised, but with selective military loading preprogrammed to

optimize unit payloads, can provide a major portion of the airlift with only a minor increase in the organic fleet. The military benefit of Civil Reserve Air Fleet (CRAF) is generally well defined and accepted. Achievement of carrier participation is the remaining requirement, involving operational issues and incentive agreements, among others.This contract did not address those issues.

The convertible freighter with provisions to convert both to passenger and Enhanced CRAF configurations are attractive Design Options. However, because of conversion requirements - passenger and CRAF - these options may be at a disadvantage on a comparative cost basis. None of the drive through options appeared to provide a cost effective capability, largely due to a lack of improved military benefit which can be attributed to drive through capability.

Depending on the level of military capability required, commercial costs for the Design Options can range from zero to significant. The issue is how much military capability is needed in CRAF if an organic fleet exists.

One of the most pervasive influences in the study was the cost of the Enhanced CRAF provisions on the Design Options airplanes. Commercial pricing was used for both the baseline airplane and the CRAF provisions. However, because the CRAF provisions were developed and procured on a small unit buy relative to the baseline airplane, the relative cost of the CRAF provisions are high, and significantly influence the results.

In order to provide the technology development for the Intertheater Airlift Vehicle (IAV)[1] the Air Force and the NASA should expedite the advanced structures development necessary to make the concept economically attractive to the commercial carriers.

1. IAV has previously been called C-XX and is the genaric name currently used in the MAC Statement of Need (SON).

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GLOSSARY

ASD/XRH	Aeronautical Systems Division, Conceptual Systems Design Directorate
ACEE	Aircraft Energy Efficiency Program
ARES	Airplane responsive engine selection
ASM	Airplane seat-mile
BCAC	Boeing Commercial Airplane Company
BMAC	Boeing Military Airplane Company
BMAD	Boeing Military Airplane Development organization
CL	Centerline
CRAF	Civil Reserve Aircraft Fleet
DCF	Dedicated commercial freighter
DCP	Dedicated commercial passenger aircraft
DMF	Dedicated military freighter
DOC	Direct operating cost
ECF	Enhanced Commercial Freighter
ECP	Enhanced Commercial Passenger
EET	Energy-efficient transport
FOM	Figure of merit
FRG	Federal Republic of Germany
GR/EP	Graphite-epoxy
GW	Gross weight
H/C	Honeycomb
IAV	Intertheater airlift vehicle
IADS	Innovative aircraft design study
IOC	Initial operational capability

LCC	Life cycle cost
LCN	Load classification number
LE	Leading edge
LRC	Long-range cruise
MCRAN	Military-commercial range
MFG	Manufacturing
MIL	Military
MLA	Maneuver load alleviation
MOD	Modification
NASA	National Aeronautics and Space Agency
NATO	North Atlantic Treaty Organization
NM, NMI	Nautical mile
P/L	Payload
PSF	Pounds per square foot
R&D	Research and development
RFP	Request for proposal
ROI	Return on investment
RPM	Revenue passenger-mile
RSS	Relaxed static stability
RTM	Revenue ton-mile
SAS	Stability augmentation system
SCAR	Extra weight included for future installation of equipment or structure.
SLST	Sea level static thrust
SM	Statute mile
SON	Statement of Need
TO	Takeoff
TOFL	Takeoff field length
TOGW	Takeoff gross weight

UE	Unit Equipment
W/XXX	With xxx
W/O	Without
ZFW	Zero fuel weight

ACKNOWLEDGEMENT

This document, the Design Options Study final report, presents the detail data and results generated during the program. The study was performed for the Air Force Systems Command, Aeronautical Systems Division, Development Plans, (ASD/XRP) Wright Patterson Air Force Base, Ohio, by the Boeing Military Airplane Company, Seattle, Washington, under contract F33615-78-C-0114.

Dr. Larry Noggle, ASD/XRP, directed the program for the Air Force.

The Boeing study effort was directed by Mr. E. A. Barber, Air Force and Navy Development Manager. D. G. Blattner was the study manager; F. D. Castleman was responsible for the design options evaluation; R. J. Marhefka was the Technology Staff manager. Principal technical and cost contributors were: M. Fligstein, S. Jensen, D. Robesch, J. Lium, L. DeCan and L. Landkamer.

1.0 INTRODUCTION

The Boeing Company viewed the Design Options Study as a natural extension of the 1976 and 1977 Innovative Airplane Design Studies (IADS) which were also conducted for the ASD/XRP. The IADS studies provided the basis from which the Design Option Studies were derived.

The Design Options Study was performed by the Air Force and Navy Programs Group, the Boeing Military Airplane Company, under the direction of E. A. Barber, Figure 1.1. The Study Manager was D. G. Blattner, and the Technology Manager R. J. Marhefka. This group has also performed the New Strategic Airlift Concepts Study for the Flight Dynamics Laboratory and the airplane design tasks for the Navy Maritime Patrol Aircraft contract.

IADS 76, was a study of broad scope which examined such diverse subjects as alternative fuels and the use of a transport to carry ballistic missiles, Reference 1.1. It focused on an extremely large transport, which weighed 1.5 million pounds, but also provided a substantial base of parametric design data with variations in payload and range, and a well defined technology base for use in designs to be operational in 1990 and later, Figure 1.2. More significantly from the point of view of the Design Options study, it provided the initial insight into the problems and benefits associated with commercial/military commonality.

The outgrowth of IADS 76 was IADS-77, which was to focus almost exclusively on commercial commonality. IADS-76 had concluded that using a moderate technology base would not provide for great reductions in direct operating costs. IADS 77 established, by way of a comprehensive market analysis, that the most promising markets large enough to initiate a new airplane program were in fact occupied by current aircraft, primarily the 747, Reference 1.2. Payloads from 200,000 to 300,000 lbs were identified as desirable, with ranges from 3000 to 4000 nmi required. It was determined that in order to penetrate the existing fleet, a reduction of 20% in direct operating costs was required. This requirement could only be achieved by advanced technology, primarily in the area of advanced graphite epoxy structure, Figure 1.3. IADS 77 also identified the fundamental aspects of commercial commonality, provided

initial designs for commercial/military versions of a baseline commercial transport, as well as identifying kits with which to convert the CRAF commercial design to military capability.

The objective of the Design Options Study was to consider a number of alternative approaches by which commercial/military commonality could be achieved. Those approaches and the relationship of the two IADS studies are shown on Figure 1.4.

More specifically, the study objectives are those shown on Figure 1.5: identify, develop and evaluate design options whereby the conversion from a civil transport could be made. More general objectives are those shown in Figure 1.6 : to minimize the penalties associated with the conversion, and maximize the benefits to the military user thereby balancing the costs and benefits in an equitable manner.

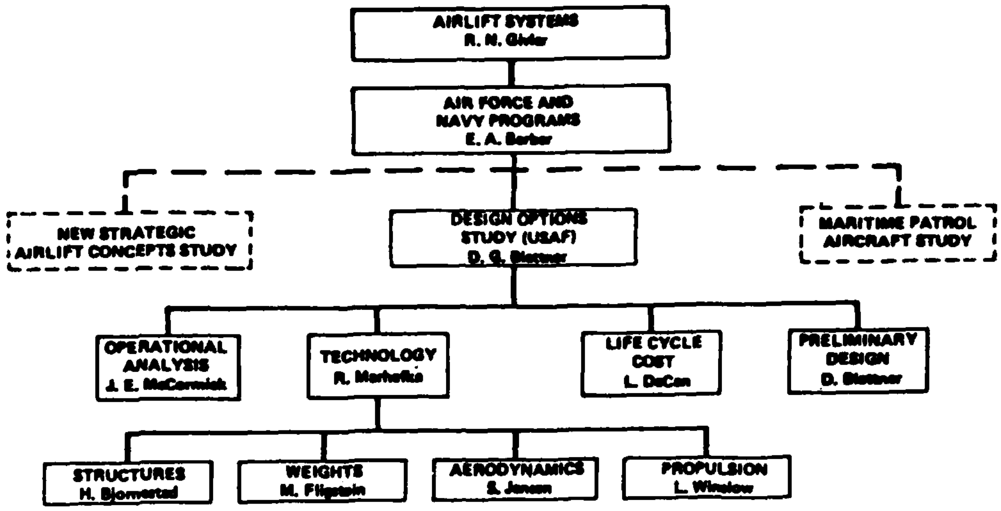


Figure 1.1. Boeing Military Airplane Company, Airlift Systems Organization

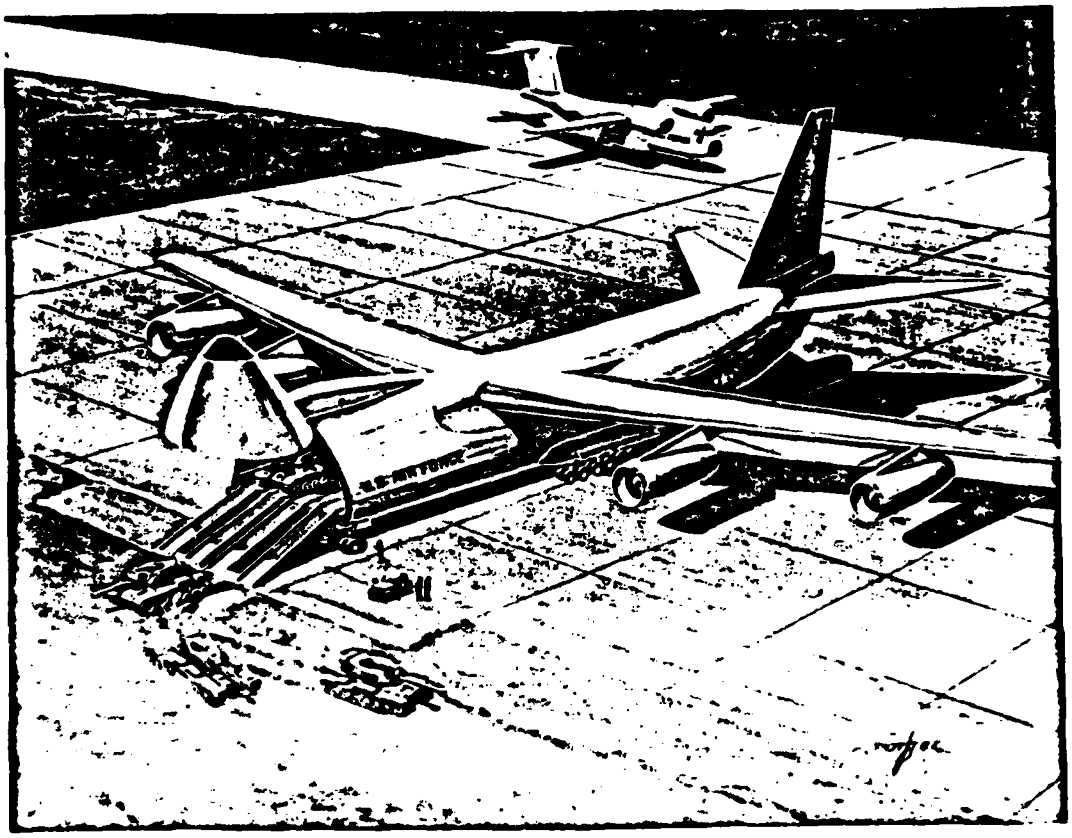


Figure 1.2. IADS 1976 Baseline Airplane-Four Cargo Lanes

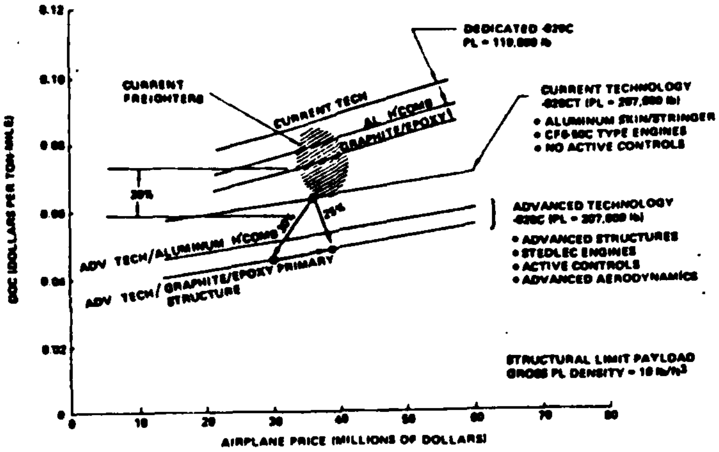


Figure 1.3. IADS-1977 Comparative Economics, 1985 Technology

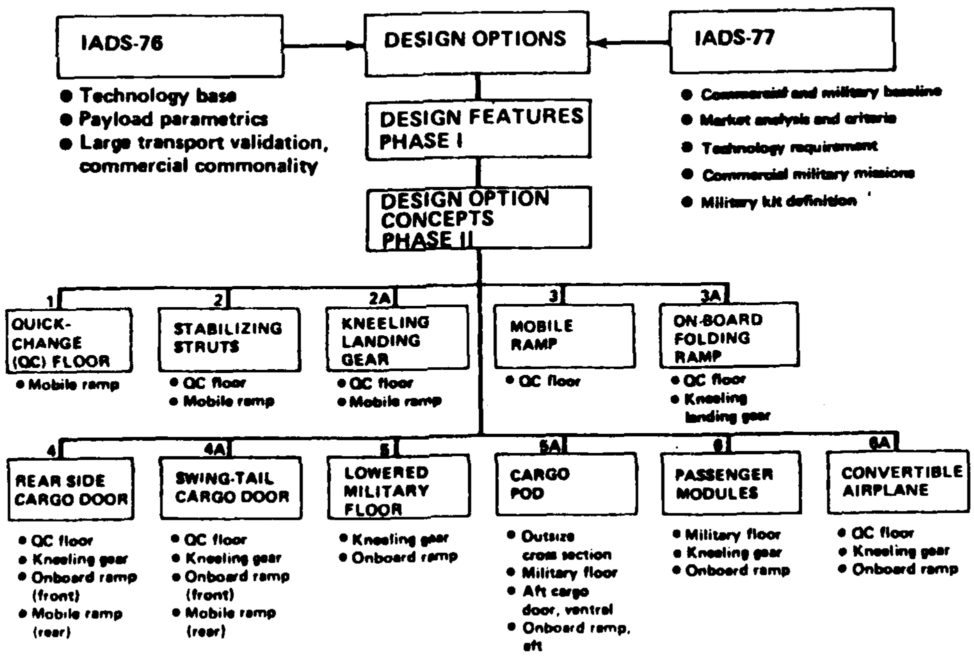


Figure 1.4. Study Relationships

- Identify alternative approaches for providing the military design features desired by Headquarters, Military Airlift Command, in a next-generation strategic airlift transport. (Ref: C-XX concept paper, Hq MAC, 1974)

- Develop preliminary designs for several of the alternatives (design options) selected by the USAF program manager. The designs shall be applied to a C-XX type military-commercial transport selected by the contractor, and shall be in sufficient detail for determination of weight, cost, and functional suitability.

- Evaluate the impact of each design option on the mission performance and cost of military and commercial models of the baseline transport. The military evaluations shall be based on aircraft fleet performance, size, and cost for specified NATO and Mideast deployments.

- Identify technologies required to permit retention of military mission-related design features.

Figure 1.5. Study Objectives

- Maximum simplicity
- Minimum cost
- Minimum "scar" weight—commercial mode
- Minimum installed weight—military mode
- Minimum conversion time, commercial to military
- Minimum loading time

Figure 1.6. General Design Objectives

2.0 BACKGROUND AND APPROACH

The study was divided into two Phases, the first of which was conceptual in nature, followed by the more design oriented Phase II.

The contract work statement specified 10 military features which have generic military benefit in military airlift, Figure 2.1. The task in Phase I was to postulate design alternatives, or "options," as ways to accomplish these features. Boeing proposed to study in Phase II those features and options highlighted on Figure 2.1.

The approach was new in that a comparative analysis was required to evaluate each option, not only from the point of view of military benefit, but also from that of identifying the commercial cost. For each Design Option, a conversion kit was postulated so that with the kit installed the transport would be capable of achieving the military capability inherent in the feature which the option provides. Each kit was defined and integrated into the baseline CRAF transport. The performance of the transport over the postulated NATO and Mid East missions was then determined. The payload, mission fuel, loading time, conversion time and block time were used to determine the productivity, military fleet size and cost. In a like sense, the non-productive weight was used to determined the penalties incurred by the commercial carriers in using Enhanced CRAF models rather than the Dedicated Commercial Models. A dedicated military freighter was also defined to provide a basis of comparison with the enhanced CRAF Military capabilities. A schematic of the Phase II approach is shown on Figure 2.2.

The design approach shown on Figure 2.3 was of particular use in defining the number of variations which would be postulated for the Intertheater Airlift Vehicle (IAV). The basic design is perceived to spin off the dedicated military, dedicated commercial and the Enhanced CRAF models. In addition to the models shown in Figure 2.3, an enhanced CRAF passenger convertible and a Dedicated Commercial Passenger airplane were also configured .

Military feature or capability	Design options						
					USAF selections for phase II		
Truck bed height	Kneeling landing gear	Stabilizing struts	Transportable ramp	Elevator lift	Onboard loader	General ramp	Ramp-loader combination
Reinforced flooring	Palletized floor—special	Pallestized floor—463L	Floor modules	QC floor panels	Passenger modules (passenger commonality)		
Drive-through loading	Rear ramp and door	Swing tails	Clamshell rear doors	Rear side cargo door			
Outsize cross section	Lowered floor *	Folding floor	Cargo pod				
Navigation aids	Wiring added	Autonomous data bus	Central control panel	Antennas	Black box		
Pallet loading systems	Powered floor	Provisions for powered floor	Air cushion pallet	Air-cushion floor	Winch and cable	Overhead power drive system	
Aerial refueling	Bulk fuel cells	Palletized lower deck tanks	Palletized main deck tanks				
Short takeoff and landing	Change engines	Jet-assisted takeoff	Upper surface blowing	Reduce payload			
High engine noise reduction	Removable proofing						
High-flotation landing systems	Change landing gear	Larger nose gear					

*In lieu of folding floor

Figure 2.1 Phase I Summary

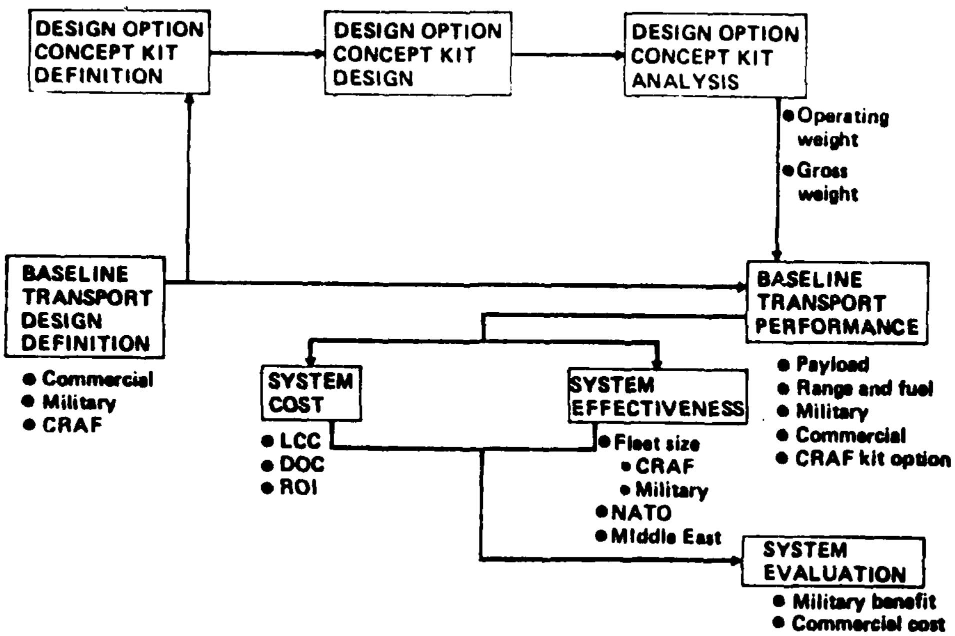


Figure 2.2 Approach - Phase II

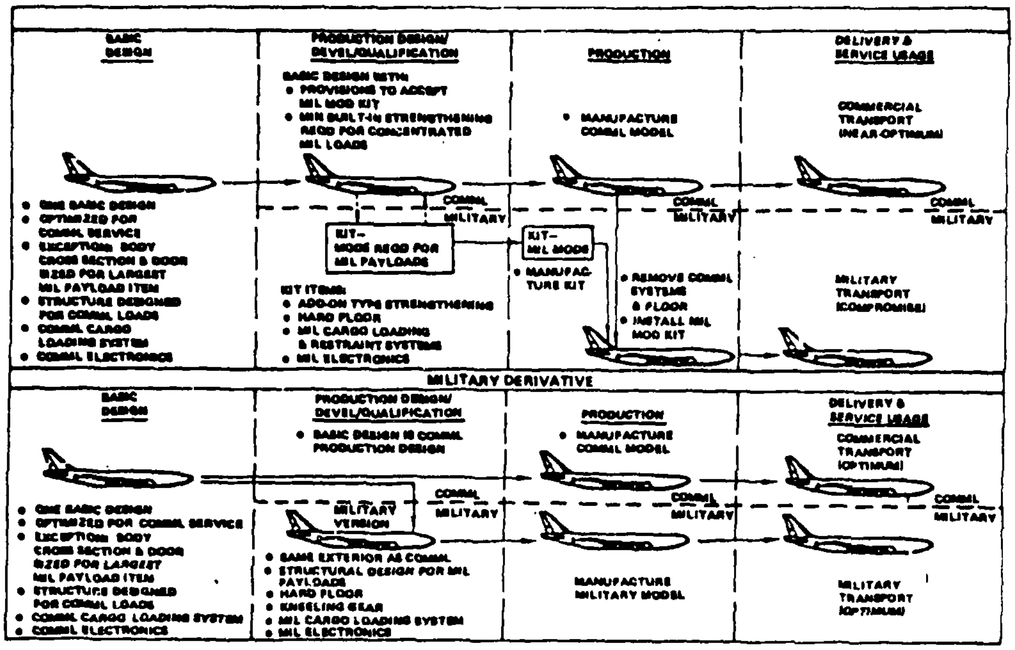


Figure 2.3 Intertheater Airlift Vehicle (IAV) Design Approach

The Enhanced CRAF differs from the DCF in that it contains, as a part of its permanent structure, fittings which allow a kit to be installed, to provide whatever military feature is desired. The analysis and evaluation then compared the Enhanced CRAF transports - both of which were compromised - to the uncompromised DCF and DMF.

An analysis was required which was both simple enough to be economical and yet broad enough to adequately represent the intrinsic properties of the problem. Figure 2.4 is useful in representing the basic principles of the analysis which was devised. First it was necessary to set the military requirement in terms of the need to meet the particular scenario of interest, generally in terms of the number of ton miles per day required. It was also necessary to represent the type of cargo such as passengers, bulk, oversized and outsized. The passenger and bulk components were fixed at a particular level and assumed to be carried by the DCP and DCF respectively. Note that for the sake of simplicity it was assumed that only the IAV handled the total requirements; no other designs were involved. Subtracting the freight and passenger or commercial requirement from the total requirement left the increment which must be provided by the Enhanced CRAF and the organic fleet. It was further assumed that the Enhanced CRAF fleet was fixed at some number of aircraft which represented real world market conditions. This fleet size then remained fixed as the different design options, each having different military capabilities, were evaluated. The number of military organic DMF required were then determined as a function of the design option. As an example, if, Option A had more military payload or was more responsive to the scenario than option B, the total Enhanced CRAF fleet was more mission effective and hence fewer organic transports were required. As a result the military life cycle cost which includes the transport acquisition and the kit cost would be less. This procedure enabled cost trade-offs to be made between the sizes of the organic and enhanced CRAF fleets.

In this way the military life cycle cost was coupled to the design option and through it and its commercial penalties, to the direct operating costs, Figure 2.5.

- CRAF FLEET FIXED
- ENHANCED CRAF FLEET FIXED
- ORGANIC FLEET VARIABLE

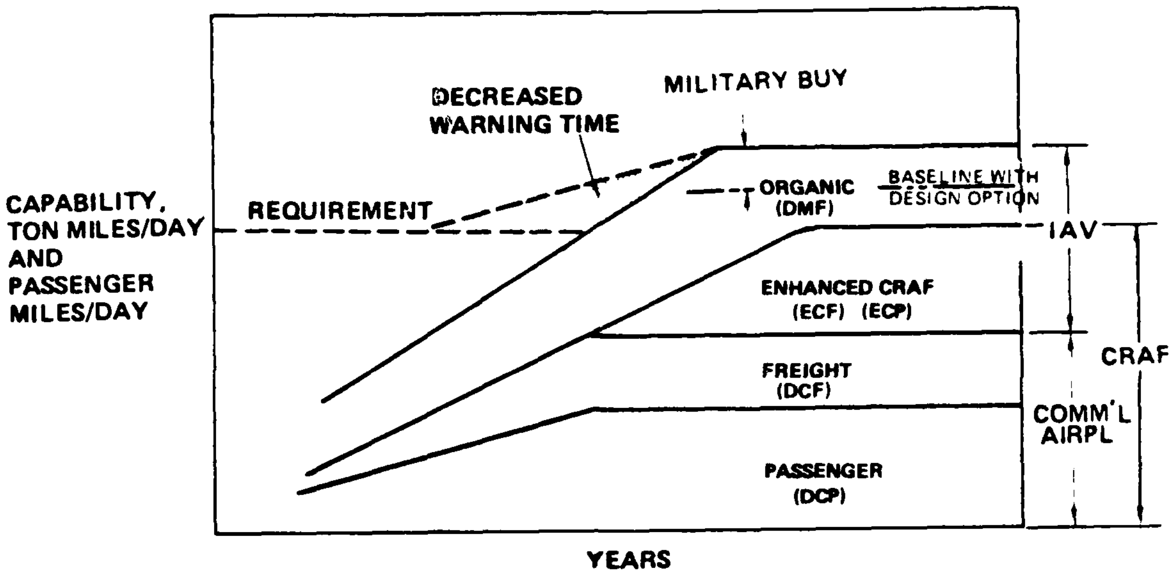


Figure 2.4 Approach - Evaluation

- SELECT MILITARY TOTAL REQUIREMENT~ SCENARIO.
- FIX PASSENGER AND FREIGHT SEGMENT TO MEET MILITARY REQUIREMENT FOR TROOPS AND BULK.
- ASSUME BALANCE OF MILITARY REQUIREMENT IS MET BY THE IAV.
- FIX THE ENHANCED CRAF FLEET SIZE.
- DETERMINE ORGANIC CAPABILITY AS THE DIFFERENCE IN THE IAV REQUIREMENT.
- AS THE CRAF CAPABILITY TO CARRY MILITARY CARGO INCREASES, THE ORGANIC NEED DECREASES.
- DETERMINE THE FLEET SIZE AND LIFE CYCLE COST OF THE ORGANIC FLEET.
- DETERMINE THE DOC, ROI OF THE COMMERCIAL FLEET.

Figure 2.5 Approach - Evaluation (continued)

3.0 BASELINE AIRPLANE

3.1 Introduction and Requirements

An artist's drawing of the baseline airplane selected for the design options study is shown on Figure 3.1.1. The baseline airplane was designed for production in dedicated commercial, dedicated military and the subject of this study Enhanced CRAF models. All models had the same exterior configuration, engines, and high commonality between civil and military versions. A low wing configuration was selected for the following reasons: 1) safer ditching characteristics, 2) passenger preference, 3) facilitates main landing gear installation, and 4) military payload space is not obstructed by wing carry-thru structure as in conventional high wing military transport designs. Functional requirements and configuration ground rules for the baseline airplane and its various models are summarized on Figure 3.1.2. An I.O.C. of 1990 was projected for the aircraft, based upon a 1985 technology maturity date for the key technologies.

The military requirements included a 3600 n.mi. range and 240,000 pound payload providing the capability to carry two main battle tanks. The military version was operated at a load factor n = 2.25 when the full two-tank payload-range capability was desired. To satisfy this requirement, the maximum design takeoff gross weight was 588,000 pounds.

The gross weight of the commercial version was 522,000 pounds and the design load factor n = 2.5. The design payload was 200,000 pounds. The commercial payload was matched with the military cargo box requirements such that the design cargo density was 10 lb/ft^3 at the design payload weight of 200,000 pounds. The ATA range capability, 3140 nautical miles, resulted from having specified the gross weight and payload for the commercial freighter.

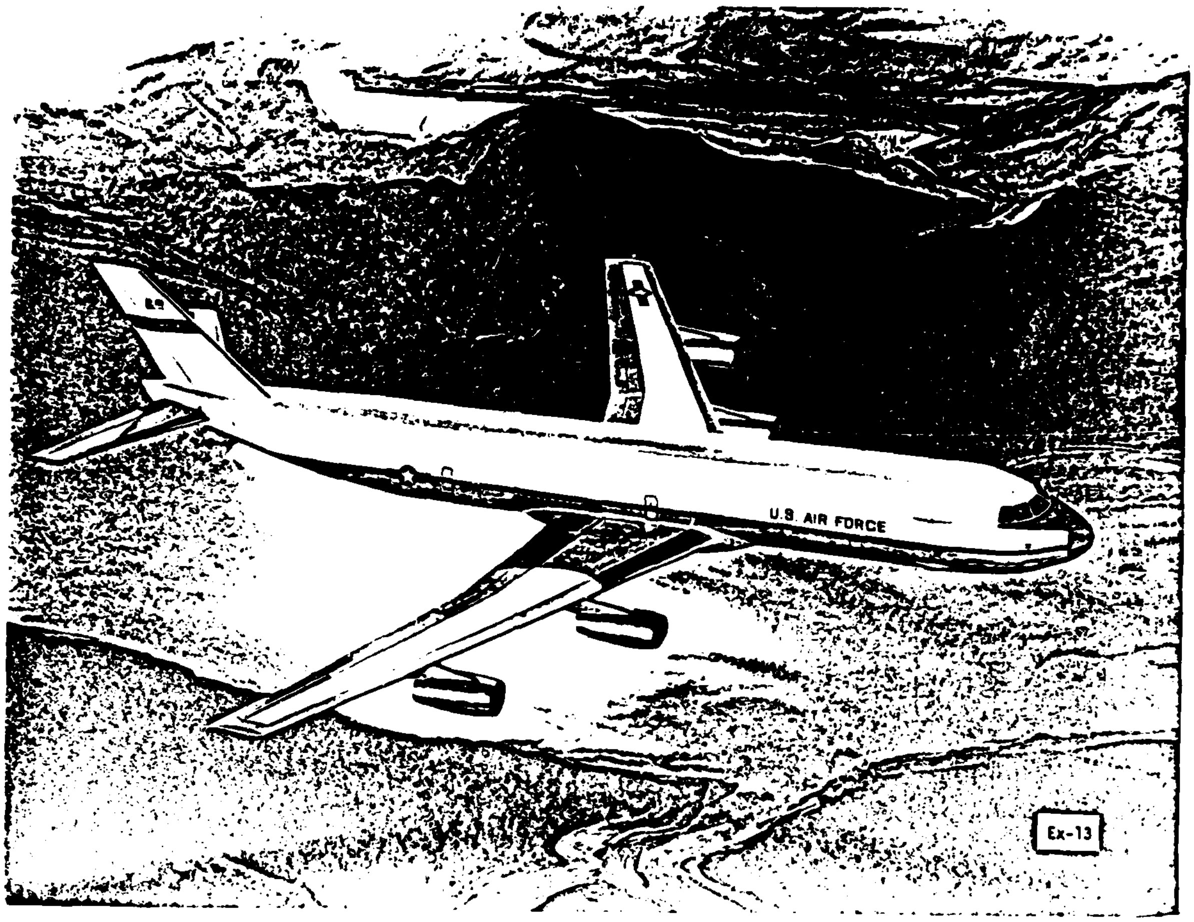


Figure 3.1.1 Baseline Military/Commercial Airplane

- **Designed for production in dedicated commercial, dedicated military, and CRAF models:**
  - **Military conversion kit is stocked to permit rapid conversion of CRAF models for military service.**
- **All models have same exterior configuration and high commonality between military and commercial versions:**
  - **Same engines**
  - **Same zero fuel and takeoff gross weights**
- **Military payload provisions (dedicated and CRAF models):**
  - **Outsize capability including M-60 tanks**
  - **Cargo loading system**
  - **Pressurized fuselage**
  - **Front ramp**
  - **Nose cargo door**
  - **Kneeling landing gear**
- **Commercial freighter payload provisions and capabilities:**
  - **Accommodates 8-by8-ft main deck cargo containers, two abreast**
  - **Mechanized cargo loading systems, main deck and lower lobe**
  - **LD-3 containers carried in lower lobe, two abreast**
  - **Nose cargo door**
  - **Pressurized fuselage**
- **Commercial passenger models:**
  - **425 passengers on main deck, mixed class**
  - **LD-3 containers carried in lower lobe, two abreast**
  - **707/727 comfort standards**
- **Landing gear flotation characteristics equivalent to 747**
  - **LCN 30 to 70**

Figure 3.1.2 Baseline Airplane Design Characteristics

The commercial mission profile selected was the ATA International mission with provisions for traffic allowances, holding, and diversion to alternate airfields. For military aircraft, mission performance was based upon MIL-C-5011-A rules. A minimum initial cruise altitude of 30,000 feet was selected for commercial and military versions. Takeoff field lengths selected were: 10,000 feet FAR commercial and 8,000 feet military critical for sea level standard day conditions.

Engine-out climb gradients of 3.0 percent were specified for commercial operation. Positive engine out gradients were required for the military versions. Cruise speeds desired are those which are compatible with existing commercial traffic.

A primary requirement for the baseline commercial freighter was that it must provide direct operating costs at least 20 percent lower than current freighters, Reference 1.2. These lower direct operating costs are deemed mandatory if penetration of the 1990 commercial market is to be achieved. Use of advanced technology and careful attention to design selection rationale are essential in order to accomplish these goals.

Design characteristics of the baseline airplane are discussed in Section 3.2. Section 3.3 describes the payload arrangements and provisions. Technology and performance are summarized in Sections 3.4 and 3.5. The selection rationale, including design figure-of-merit trade data, is presented in Section 3.6.

3.2 Baseline Airplane Description

The principal versions of the Design Options Study baseline airplane are (a) Dedicated Commercial Freighter (DCF), (b) Dedicated Commercial Passenger (DCP) transport, (c) Dedicated Military Freighter (DMF), (d) Enhanced Commercial Freighter (ECF), and (e) Enhanced Commercial Passenger (ECP). The CRAF versions each have two configurations (1) commercial and (2) with the military kit installed. A three-view of the baseline military/ commercial freighter is shown on Figure 3.2.1.

	Military, 2.25g	Commercial, 2.5g
Range (nmi)	3,000 (military rules)	3,140 (ATA)
TOGW (lb)	588,000	522,000
ZFW (lb)	445,560	398,630
Payload (lb)	240,000[a]	200,000[a]
Cruise speed	M = 0.80	
Wing area (ft^2)	3,730	
Sweep	33 deg	
AR	7.8	
Engines (SLST), lb	4 at 33,000	
Technology level/IOC	1986/1990	

[a]Dedicated versions; less for CRAF models.

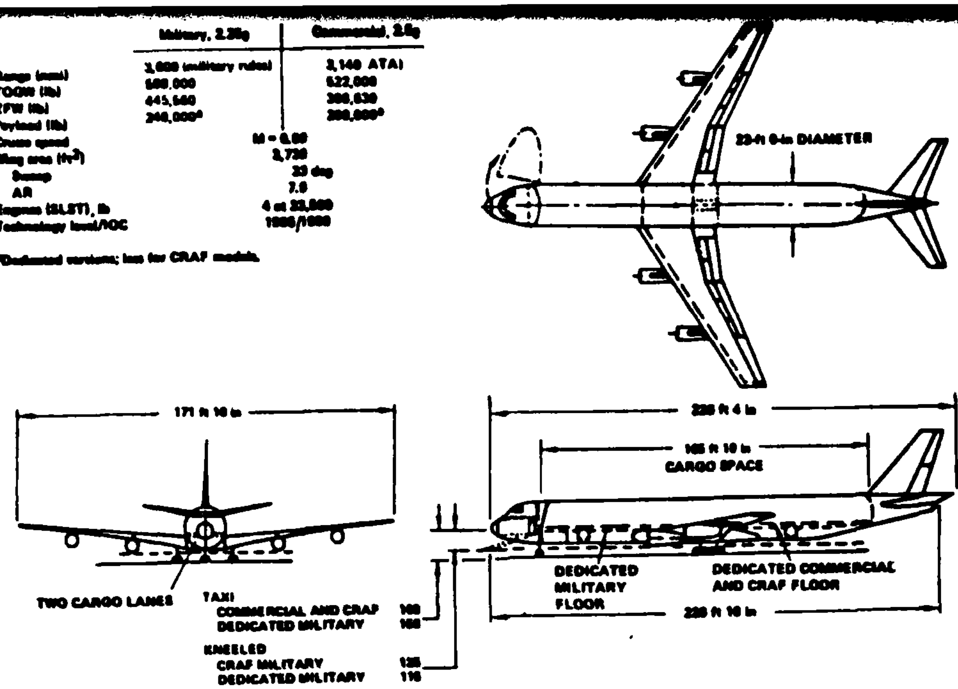


Figure 3.2.1 Baseline Military/Commercial Freighter

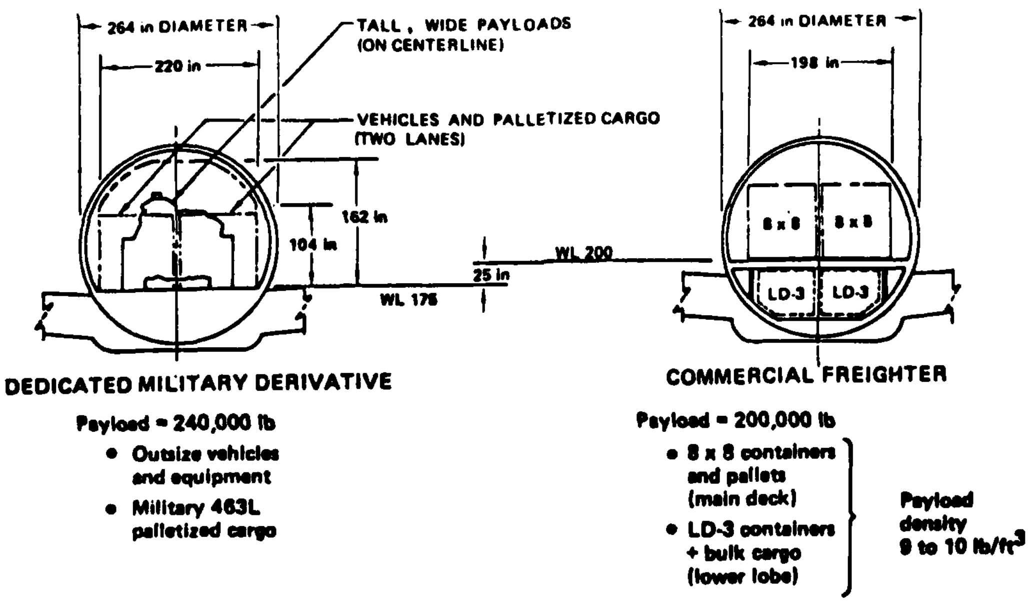


Figure 3.2.2 Baseline Airplane Cross Section

The design options baseline airplane was derived from studies conducted for the Innovative Aircraft Design Study (IADS) 1977, Reference 1.2. The starting point was the military/commercial range airplane, designated "MCRAN" in Reference 1.2, with a 200,000 pound payload capability at 3600 nautical mile range. Commercial design figures-of-merit used in the optimization studies for the MCRAN configuration were reviewed and are discussed in Section 3.6. The IADS selections for the wing, thrust, and gross weight characteristics were based upon a compromise between minimum direct operating cost and minimum flyaway cost, and further refined for the updated airplane.

A circular fuselage cross-section was adopted for the Design Options Study baseline airplane due to pressurization, fatigue life, and minimum weight considerations. The 264 inch diameter size selection makes possible efficient utilization of the cross-section for both military and commercial payloads. Figure 3.2.2 illustrates this point for the dedicated military and commercial freighter versions. The cargo floor was lowered 25 inches in the dedicated military derivative for increased payload height capability. Length of the payload compartment was approximately 166 feet in all freighter models.

Payload capability of the dedicated military freighter was 240,000 pounds of vehicles and/or cargo. Two main battle tanks can be carried. Palletized cargo capacity was 39 military 463L pallets. The design floor loading was 80 lb/ft^2 for the military freighter.

A commercial passenger version accommodates 425 mixed class passengers with baggage and 57,400 pounds of cargo housed in LD-3 containers in the lower lobe.

The horizontal swing nose cargo door provided the following advantages compared to a 747 or a C-5A type high cab and visor door arrangement: (a) full height of the body cross-section was available for tall payloads; (b) most of the nose volume can be used, with the flight deck on the upper level and off-duty crew quarters below; (c) potential for reduced weight

and drag. Feasibility of the horizontal swing nose cargo door was enhanced by the fly-by-wire flight control system. Additional studies are needed to define the swing nose, investigate its pros and cons, and prepare a comprehensive overall evaluation.

A three-post main gear was selected on the basis of minimum operating weight and simplicity. Main gear steering was not required using the arrangement shown. A kneeling version of the fixed-length commercial gear was provided on the dedicated military airplane. Floor height above ground of the military model was 13.2 feet in normal configuration and 9.6 feet when kneeled. The commercial cargo floor height was approximately 14 feet. Landing gear flotation characteristics were equivalent to those of the 747, with LCN's of 50 to 70, depending on gross weight, Figure 7.1.7. Principal characteristics of the baseline airplane are summarized on Figure 3.2.3.

3.3 Payload Arrangements and Provisions, Baseline Airplane

Payload arrangements and provisions are described in this section for the Dedicated Military Freighter, Dedicated Commercial Freighter, and Dedicated Commercial Passenger versions of the Design Options Study baseline airplane. Payload arrangements for Enhanced CRAF airplanes incorporating the design options of Section 4.0 were based on the arrangements described for the dedicated military and commercial models.

3.3.1 Payload Arrangement and Provisions, Dedicated Commercial Freighter (DCF)

Basic sizing and arrangement of the study baseline airplane fuselage was determined primarily by payload requirements for the commercial freighter and passenger versions. This design policy was dictated by the importance attached to good commercial airplane economics, and acceptance of the commercial models by the airlines. The high degree of design commonality evident in the fuselage internal arrangement of all versions reduces development and production costs of all models, which will increase the total program buy.

• Military and commercial transport—dedicated and CRAF versions	
• Payload and range—military —commercial	240,000 lb for 3,600 nmi 200,000 lb for 3,140 nmi
• Takeoff gross weight—military —commercial	588,000 lb ($n = 2.25g$) 522,000 lb ($n = 2.50g$)
• Cruise mach number	0.80
• Takeoff field length	8,000 ft (nominal)
• Military outsize vehicle capability	Main battle tanks
• Commercial design cargo density	9 to 10 lb/ft^3
• Principal versions	a. Dedicated commercial freighter b. Dedicated commercial passenger c. Dedicated military freighter d. CRAF commercial freighter (Δ OW includes scar weight) e. CRAF military freighter (CRAF commercial freighter with military kit installed)
• Technology level and initial operational capability	1985-1990

Figure 3.2.3 Baseline Airplane Description

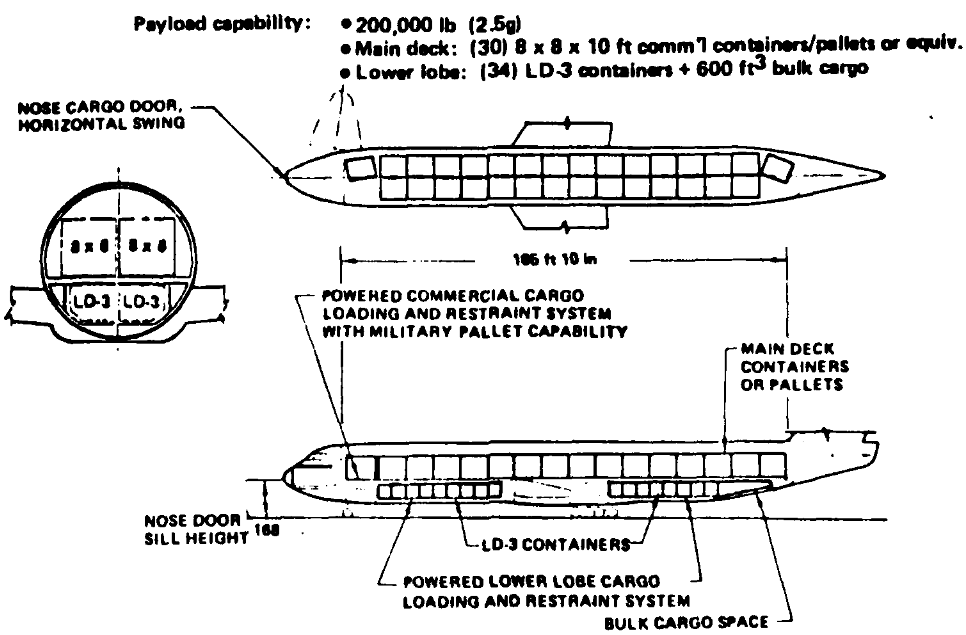


Figure 3.3.1 Payload Arrangement and Provisions Dedicated Commercial Freighter

Design payload items for the commercial freighter are International Air Transport Association (IATA) commercial cargo containers or loaded pallets 8 X 8 feet in cross-section, and LD-3 baggage/cargo containers. The cross section view in Figure 3.3.1 shows the fuselage/floor configuration developed to accommodate these payloads. The other views show the arrangement in the airplane of 30 main deck containers each 10 feet in length, plus 34 LD-3 containers in the lower lobe. Bulk cargo space was available aft of the containers in the lower lobe. Twenty or forty foot main deck containers can be carried in place of ten foot units at appropriate locations. Other container/pallet types and sizes also can be accommodated. The number of containers to be carried, and hence the cargo compartment length, was determined by the design payload weight of the commercial airplane and average density of the revenue cargo. Compatibility of the resulting cargo floor area with that required for the Dedicated Military freighter airplane was checked and found satisfactory.

Improved versions of the 747 cargo loading/restraint systems were provided on the main deck and lower lobe cargo floors. Capability for powered movement of containers/pallets is currently built into these systems.

Additional payload-related features in the dedicated commercial freighter include: 1) pressurized payload compartments, 2) controlled temperature and humidity, and 3) APU.

Onboard systems to facilitate cargo loading/unloading beyond the cargo door sill were not provided in the commercial freighter. Ground based loading equipment appears to be more cost effective for airline freighter operations.

3.3.2 Payload Arrangement and Provisions, Dedicated Military Freighter (DMF)

Payloads to be transported by military versions of the Design Options baseline airplane are: 1) military vehicles, outsize and smaller; 2) mobile weapons and equipment; 3) palletized cargo on military 463L pallets. Capability for accommodating commercial containers and pallets is desired also. However, the military payload capability judged to be of primary importance in this study is drive-on loading/unloading and transport of outsize vehicles and equipment, including main battle tanks.

The cross-section view in Figure 3.3.2 shows how the baseline airplane design was adapted to maximize the military payload envelope size in the dedicated military version. The wing and cargo floor was lowered 25 inches on the fuselage compared to the wing/floor locations on the baseline. The payload envelope shown accommodates two military pallets abreast, or two standard highway width vehicles such as 2 1/2 ton M35 army trucks. Tall, wide payloads are carried on the fuselage centerline. In this way, all but a few percent of the current Army division vehicle/equipment types can be accommodated.

The baseline cargo compartment length was well suited for the military airplane application. Average military cargo floor loading was about 81 lb/sq foot at the 240,000 lb design payload weight and 2940 sq ft floor area. Thirty-nine military pallets can be carried.

A hard, strong cargo floor was provided. Its design was optimized for the concentrated wheel and track loads of the military vehicles. An optimum arrangement of the floor substructure was used since lower lobe cargo space is not required. Tiedown points and flipover roller trays for the military cargo loading system were built into the floor. The cargo loading/restraint system was designed for military pallets, with provisions to accommodate other types of pallets and containers. A winch was provided for pallet loading/unloading as in current military transports.

The baseline horizontal swing nose cargo door was retained in the dedicated military airplane. Off duty crew quarters were provided on the lower level below the flight deck. An onboard folding ramp was installed at the nose door station for self-contained drive-on loading/unloading capability. Slope of the ramp in Figure 3.3.2 is 15°. A ramp with less slope can be accommodated; the additional length required would impose weight, stowage space and cost penalties. A kneeling version of the baseline fixed length landing gear was used to minimize loading ramp length.

Payload capability:
- 240,000 lb (2.25g)
- Outsize military vehicles and equipment
- Military 463L palletized cargo, 39 pallets

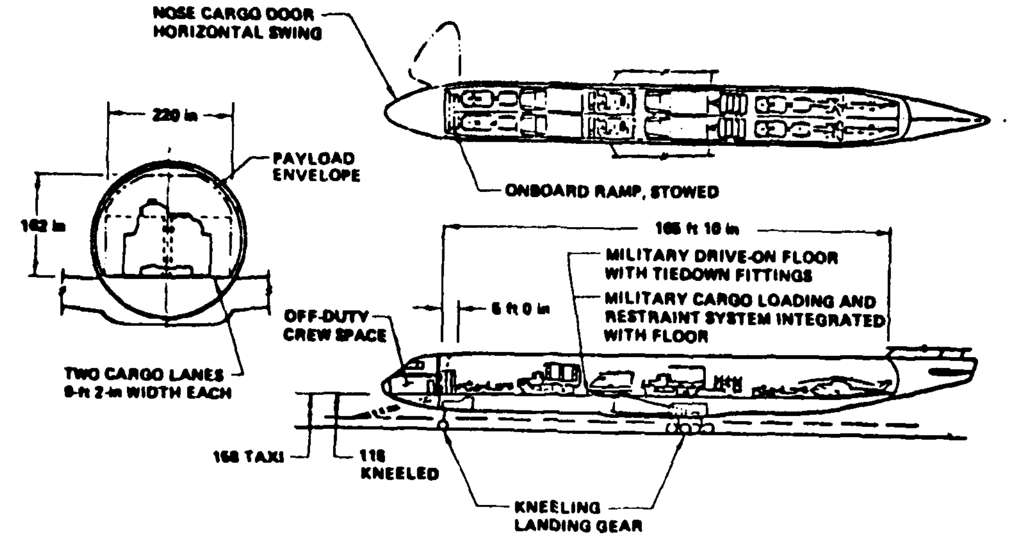


Figure 3.3.2 Payload Arrangement and Provisions Dedicated Military Freighter

Payload capability:
- 144,500 lb: passengers, baggage, and cargo (2.5g)
- Main deck: 425 passengers, mixed class, 11%/89% split
- Lower lobe: 34 LD-3 containers for baggage and cargo plus 600 ft^3 bulk cargo

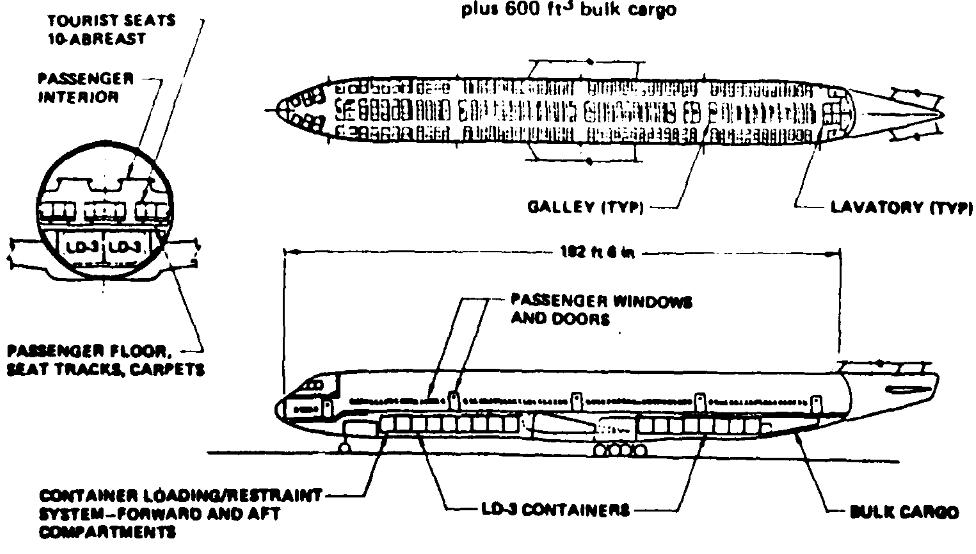


Figure 3.3.3 Payload Arrangement and Provisions Dedicated Commercial Passenger

Other payload-related baseline airplane features retained in the dedicated military version were the pressurized cargo compartment and APU. A summary list of the dedicated military freighter features is provided in Section 4.3.2 .

3.3.3 Payload Arrangement and Provisions, Dedicated Commercial Passenger Airplane (DCP)

Enhanced CRAF commercial versions of the Design Options baseline airplane were required for two of the design options studied. The dedicated commercial passenger version described in this section was developed to provide the configuration basis for those airplanes, and comparison data for use in the design options evaluations.

Fundamentally, the dedicated commercial passenger model was the same as the dedicated commercial freighter airplane described in Section 3.3.1, with windows, additional doors, a fixed nose, and passenger accommodations replacing the cargo provisions in the upper lobe. Lighter floor support structure was used in the passenger airplane due to low unit floor loading. Seat tracks were built into the floor, and additional soundproofing material was installed in the fuselage sidewalls.

The interior arrangement of the passenger airplane is shown in Figure 3.3.3. Mixed class passenger capacity was 425, with seven abreast first class seating and ten abreast tourist seating. Only 14 of the 34 LD-3 containers in the lower lobe were required to meet the baggage volume requirement for a full load of passengers. Thus considerable container volume plus bulk cargo space was available for lower lobe cargo with all seats filled.

In addition to the items discussed above, passenger accommodations and provisions included the following :seats and overhead storage units, passenger address and entertainment systems, ceilings, interior trim, carpets, lighting, galleys and lavoratories, increased electric generating capacity, oxygen system, escape slides, liferafts, and passenger type air conditioning system.

3.4 Technology

A summary of the 1985 technologies for the baseline configuration is shown in Figure 3.4.1. As applied to the baseline airplane, the uncycled improvements amount to a 25 percent reduction in operating weight and a 17 percent increase in cruise range factor relative to current technology. The available 1985 technology improvements detailed in succeeding paragraphs pertain to: 1) aerodynamics, 2) propulsion, 3) structures, and 4) active controls.

Aerodynamics technology benefits are expected to provide about 4 percent improvement in lift-to-drag ratio by 1985 relative to current technology. Two areas receiving considerable attention are advanced airfoils and wing design improvements. Renewed interest has been shown in airfoil drag level reductions and better off design performance as represented by higher lift-to-drag ratios over larger Mach number ranges. Continued efforts are being directed toward higher drag divergence Mach numbers compared to current technology levels. Similar developments are occuring in wing-body design, where reductions in interference drag are being addressed through refinements in all areas of configuration integration.

Considerable progress in reducing fuel consumption has been achieved recently, culminating with the introduction of the JT9D, CF6, RB-211 engines. The CFM-56 and JT10D engines, now under development, reflect continued emphasis on reduced SFC's as well as reduced maintenance costs. The advanced technology Pratt and Whitney STF 477 engine was used for the baseline configuration. Performance improvements include 5 percent less bare engine weight and 10 percent less fuel consumption when compared at equal values relative to current technology engines.

Improved structural efficiency through the use of advanced materials and fabrication techniques are expected by 1985, in time for an airplane I.O.C. of 1990. New aluminum alloy developments begun in the 1970-1975 time period are expected to have production status of high-purity alloys in 1979. These improved aluminum alloys are expected to result in a 5 percent reduction in the weight on the wing box. Other advancements in composite primary structure will be 15 percent to 25 percent lighter than

- **Aerodynamics**
  - **Advanced high-speed airfoils ΔM_{crit} + 0.01**
  - **Advanced aerodynamic design methods $\Delta(L/D)_{cruise}$ + 4%**
- **Propulsion**
  - **New engine** — **ΔSFC−10%**
  - **Electrical fuel control** — **ΔSFC−2%**
  - **Nacelle aerodynamic integration** — **ΔSFC−1%**
  - **Engine-nacelle structural integration** — **ΔSFC−1%**
- **Structure**
  - **Active controls** — **− 9% wing box weight**; **−20% H-tail area**
  - **Materials** — **−25% strength critical weight**; **−20% control surface weight**
  - **Advanced design methods** — **− 2% structural weight**
- **Mechanical/electrical systems**
  - **ECS/avionics cooling** — **ΔSFC−3%**
  - **Carbon brakes** — **Δwt = - 2,000 lb**
  - **Integrated actuators** — **Δwt = - 3,000 lb**
  - **High-pressure hydraulics** — **Δwt = - 3,000 lb**

  Reference aircraft

Figure 3.4.1 1985 Technology Airplane Baseline Configuration

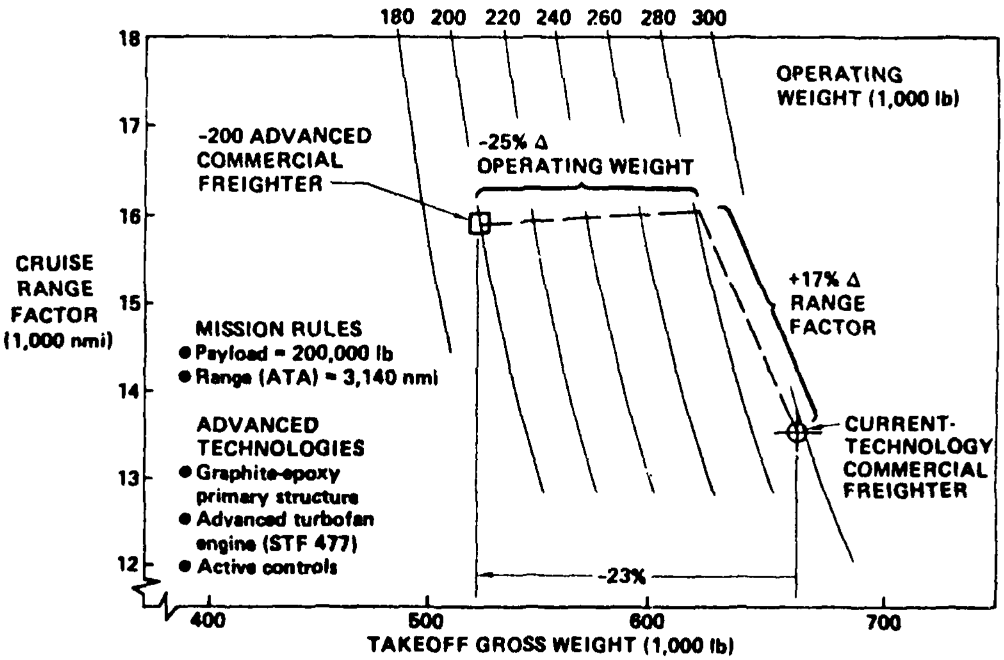


Figure 3.4.2 Benifits Benefits of Advanced Technology

current aluminum structure. Starting in the early 1980's, composites are expected to be more widely used and applied. NASA, through the ACEE program, has allocated $200 million to aid technical development. Boeing participation in the ACEE program consists of: practical development of the model 727 elevators and rudder, the 737 stabilizer, the 747 outboard aileron and one of the main landing gear doors. Special attention to lightning strike, moisture penetration and rain erosion is required for composite structure.

Metal-to-metal bonding eliminates the weight and cost of riveting and results in weight savings of strength critical primary structure. Aluminum honeycomb increases panel stiffness and allows an increase in body frame spacing, thus reducing parts. Up to 15 percent reduction in structural weight is expected using bonded structures.

The active controls used on the baseline configuration consist of maneuver load alleviation (MLA) and relaxed static stability (RSS). The MLA system shifts the center of lift inboard, resulting in 12 percent reduced wing root bending moments. The addition of a stability augmentation system (SAS) permits a 20 percent reduction in horizontal tail size because the aft limit is "relaxed" and moved more rearward. The SAS allows airplane operations with the center of gravity about 5 percent or 6 percent aft of current practice. Reductions in trim drag during cruise and reduced wing weight are additional benefits of the active control systems because of reduced downward-acting balancing tail load.

The reductions in gross weight due to technology can be shown on a design chart of range factor and operating weight, such as Figure 3.4.2. The commercial freighter is shown for the 200,000 lb payload configuration. A current technology airplane is also shown, and the technology benefits are traced to the 1985-technology baseline. As illustrated, an improvement of 17 percent in cruise range factor would reduce the gross weight by 7 percent, and the 25 percent improvements in operating weight reduces the gross weight by an additional 16 percent. The design gross weight was reduced by 148,000 lb.

In order to achieve these gains in an 1990 I.O.C. aircraft, a well structured technology development program must be initiated in the areas of propulsion/structures, and flight controls to provide confidence for the commercial sector that these advanced concepts are economical and pose an acceptable risk. A technology demonstrator program, especially in the structures area could provide the necessary levels of confidence.

3.5 Performance

A summary of the performance of the dedicated military and commercial freighters is shown on Figure 3.5.1. This figure presents field performance and fuel burned characteristics versus range. Appropriate rules, i.e., MIL-C-5011A for the military and ATA International for the commercial freighter, were used.

The weight limits for payload, the trade of fuel versus payload, and maximum fuel capacity branches of the payload-range capacity branches of the payload-range diagrams are shown.

The field performance portion of Figure 3.5.1 is for sea level, standard day conditions. This figure shows that the military version at maximum gross weight can takeoff in 9800 feet using the critical takeoff field length rules procedures. The commercial version will takeoff in 8800 feet when using appropriate FAR rules. Landing field lengths are 4200 feet when landing over a 50 foot obstacle for the military freighter. The commercial freighter FAR landing field length is 6000 feet. Landing weight for these field lengths is the normal end of mission weight made up of operating weight empty plus maximum payload and reserve fuel.

The payload delivery efficiency in terms of ton-nautical miles per pound of fuel burned are 3.3 for the military and 3.1 for the commercial freighter. Comparable delivery efficiency values for freighters utilizing current technology (as shown on Figure 3.4.2) would be 40 to 45 percent less, or 2.3 and 2.2 ton-miles per pound of fuel burned.

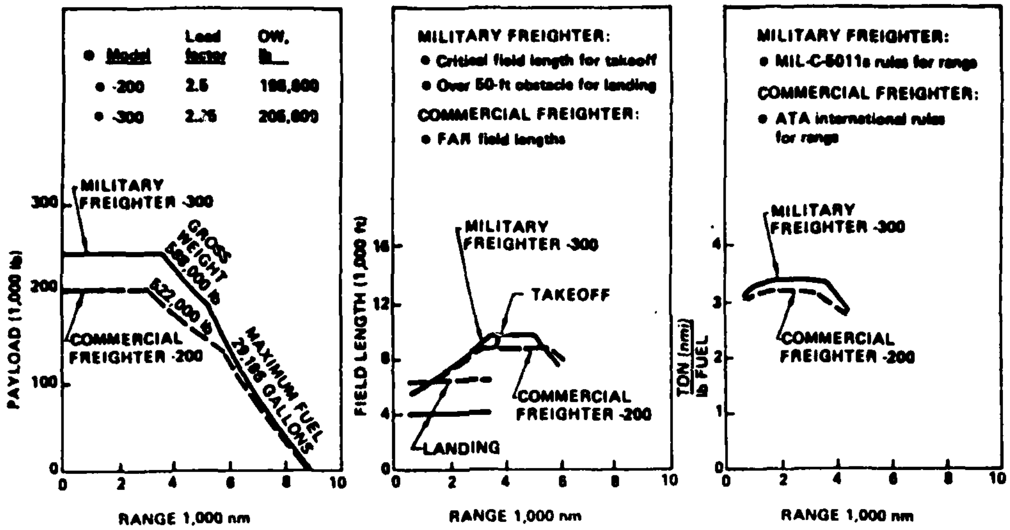


Figure 3.5.1 Performance Summary
- Dedicated Military and Commercial Freighters

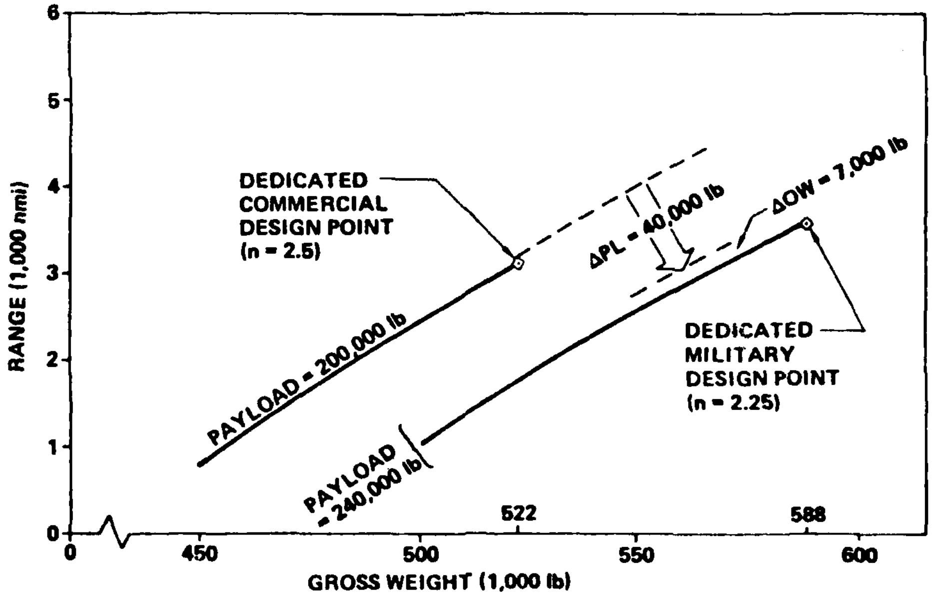


Figure 3.5.2 Design Point Relationships - Dedicated Freighters

The range-gross weight-payload design point relationships of both dedicated commercial and military freighters are summarized on Figure 3.5.2. This figure also indicates the separate effects of the payload difference and the 7000 pound greater operating weight empty of the military freighter due to the heavier floors and other military equipment.

3.6 Design Selection Rationale

Considerable attention is being paid in current studies to the appropriate choice of figure of merit in airplane configuration assessment. The effect of different figures of merit such as Direct Operating Costs, which emphasizes speed, and Acquisition Costs, which emphasizes empty weight, on configuration parameters such as wing sweep and aspect ratio can be significant. Emerging technology must, be adapted in different ways depending upon the identified application.

The Boeing Military Airplane Company organization has conducted many parametric studies as a part of military contracts and company funded IR&D work. In several recent studies, such as those reported in References 3.1 and 3.2, attention has been focused on the effect that figures of merit have on the selection of an aircraft configuration. These parametric analysis methods, as well as results from other ongoing airplane development programs, were used in selection of the baseline configuration for the Design Options Study.

The parametric analysis employed the Airplane Responsive Engine Selection (ARES) system developed by Boeing under contract with AFAPL, Reference 3.1. ARES allows simultaneous optimization of up to 10 independent parameters, resulting in rapid closure to a relatively small field of interest. A schematic of the overall approach is shown in Figure 3.6 1.

The process is initiated with a configuration drawing of an anchor point concept using estimated, but reasonable, values of design parameters defining wing size and geometry, engine size, and airplane gross weight. This definition plus scaling rules and interrelationships are prepared as inputs to an airplane matching computer program. Aerodynamics, weights, propulsion installation effects and tail sizing for stability and control

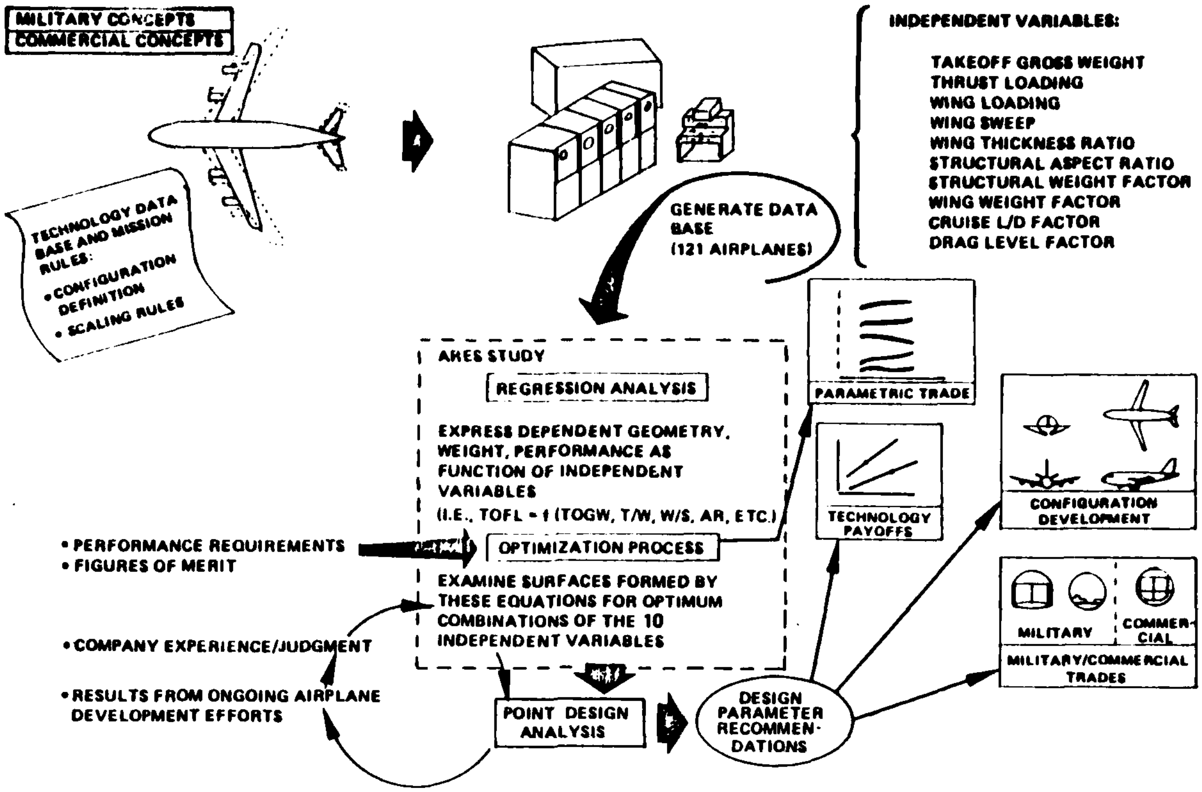


Figure 3.6 Design Selection Approach

IADS	**Innovative Aircraft Design Study–Heavy Logistics Transports (1976)**
VSTOL	**Navy Multimission Type A V/STOL (1977)**
ATS	**Advanced Tactical System (1977)**
IADS 77	**Military and Commercial Transport Commonality (1978)**
AMPA	**Advanced Maritime Patrol Airplane (1977-1979)**
ISADS	**Innovative Strategic Aircraft Design Study (1979)**

***Airplane Responsive Engine Selection (computerized optimization program).**

Figure 3.6.2 Preliminary Design Studies using ARES

considerations are also included to allow technical assessment of each design. All designs represent perturbations of the anchor point configuration varied by preselected values of up to 10 independent variables. The 10 variables in this study included six size and geometry parameters and four assessment factors used to examine the impact of technology levels.

This multi-variable preliminary design approach using the ARES data management system has been used at Boeing on studies of a wide variety of aircraft, including ship based V/STOL, supersonic fighter/attack, heavy transports, long endurance patrol aircraft and strategic bombers. Some of these studies are listed on Figure 3.6.2. The data presented in this section derive from continuing Boeing studies of the impact of advanced technology on strategic military and commercial cargo transports.

Unique to this method is the capability to compare and contrast characteristics of design points optimized to various figures of merit other than the more traditional gross weight. Design figures of merit can generally be placed in two general categories: (a) performance related, and (b) performance plus cost parameters related.

Performance related design figures of merit are: minimum gross weight, minimum fuel burned, minimum operating weight and maximum range factor designs. Performance plus cost rules leads to other design figures of merit useful in military and commercial design optimization studies. For military designs, life cycle cost, acquisition cost and the ratio life cycle cost divided by productivity are used. For commercial designs, direct operating cost, return on investment and flyaway cost are important. Military and commercial design figures of merit have traditionally included the purely performance related design figures of merit of gross weight and fuel burned. A summary of these military and commercial design figures of merit are listed on Figure 3.6.3.

The ground rules used in economic analysis were as follows. Life cycle cost was calculated for a twenty year life with a peacetime utilization of 1000 hours per airplane per year for a 200 airplane fleet in 1978 dollars.

Military	Commercial
• Life cycle cost	• Direct operating cost
• Fuel	• Fuel
• LCC/productivity	• Return on investment
• Acquisition cost	• Flyaway cost
• Gross weight	• Gross weight

Figure 3.6.3 Design Figures-of-Merit

ITEM	MINIMUM GROSS WEIGHT	MINIMUM LIFE CYCLE COST	MINIMUM ACQUISITION COST	MINIMUM FLYAWAY COST	MINIMUM LCC/ PRODUCTIVITY	MINIMUM DOC	MINIMUM FUEL
GROSS WEIGHT, lb	$\boxed{504,000}$	524,000	530,000	526,000	519,000	508,000	547,000
WING LOADING, lb/ft^2	136	128	131	121	141	142	115
THRUST/WEIGHT	0.239	0.202	0.207	0.209	0.270*	0.238	0.191
WING ASPECT RATIO							
STRUCTURAL	15*	10.2	11.0	8.5	8.5	13.2	15*
AERODYNAMIC	8.5	9.9	10.1	8.4	5.6	8.6	14.2
WING LEADING EDGE SWEEP, DEG	41	10*	17	12	36	36	13
WING MEAN THICKNESS RATIO	0.122	0.128	0.150*	0.137	0.090*	0.090*	0.090*
LIFE CYCLE COST, $B	17.7	$\boxed{16.6}$	16.8	16.7	18.0	17.7	18.0
ACQUISITION COST, $B	11.4	10.7	$\boxed{10.7}$	10.7	11.4	11.4	12.1
FLYAWAY COST, $M	43.5	40.9	40.9	$\boxed{40.8}$	43.6	43.6	46.1
LCC/PRODUCTIVITY, $/ton-mi-day	165	185	180	182	$\boxed{153}$	162	200
DIRECT OPERATING COST, $/ton-mi	0.0518	0.0567	0.0557	0.0563	0.0511	$\boxed{0.0497}$	0.0567
FUEL, lb	115,000	127,000	133,000	133,000	138,000	119,000	$\boxed{111,000}$
TAKEOFF DISTANCE, ft	8,000*	8,000*	8,000*	8,000*	7,380	8,000*	7,680
SECOND SEGMENT CEI CLIMB GRADIENT	0.060	0.045	0.051	0.044	0.030*	0.058	0.064
FAR FIELD LENGTH, ft	8,230	8,150	8,030	8,360	8,770	8,120	8,050
INITIAL CRUISE ALTITUDE, ft	35,600	31,000	31,000	31,000	33,000	35,600	34,200
INITIAL CRUISE MACH NUMBER	0.80	0.68	0.68	0.69	0.85	0.85	0.70
WING AREA, ft^2	3,707	4,094	4,046	4,350	3,680	3,580	4,757
WING SPAN, ft	117.5	201.3	202.0	190.8	143.6	175.4	260.0
SLS THRUST PER ENGINE, lb	30,110	26,460	27,480	27,480	35,940	39,230	26,120

*BOUNDARY VALUE

Figure 3.6.4 Optimized Designs - Various Figures-of-Merit

The acquisition cost was developed for a buy of 200 dedicated military airplanes from a common military-commercial development, and a total production run of 400 airplanes. The ratio of life cycle cost to productivity is a measure of cost effectiveness. However, it is considered appropriate to measure peacetime costs and wartime productivity. Consequently the value is total life cycle dollars per ton-mile per 12 hour day of wartime use.

Direct operating cost was computed for the commercial designs using the Airline Transport Association's standard international mission and 1978 cost formula. Flyaway cost is the production cost per airplane, including spares.

Military/commercial logistics aircraft design optimization studies utilizing ARES were used extensively for IADS 1977, Reference 1.2, and similar studies reported in an 1979 AIAA paper, Reference 3.2. The airplane design requirements established for these studies are similar to the Design Options baseline airplane requirements of this study. Because of these similarities, Reference 3.2 data will be directly quoted.

On Figure 3.6.4 from Reference 3.2 are listed the characteristics of airplanes optimized to seven figures of merit while constrained to the same design requirement. Note that the minimum life cycle, acquisition, and flyaway cost designs are so similar that, within the tolerance quoted, their acquisition costs are identical. These three designs simultaneously match both the 8000 foot takeoff and 31,000 foot minimum cruise altitude requirements. On the other hand, the minimum gross weight and minimum direct operating cost designs are very similar. Both designs match the 8000 foot takeoff distance requirement with nearly the same thrust/weight but the higher sweep angle of the minimum gross weight design requires a lower wing loading. The similarity of these two, as might be expected, extends to their life cycle, acquisition and flyaway costs.

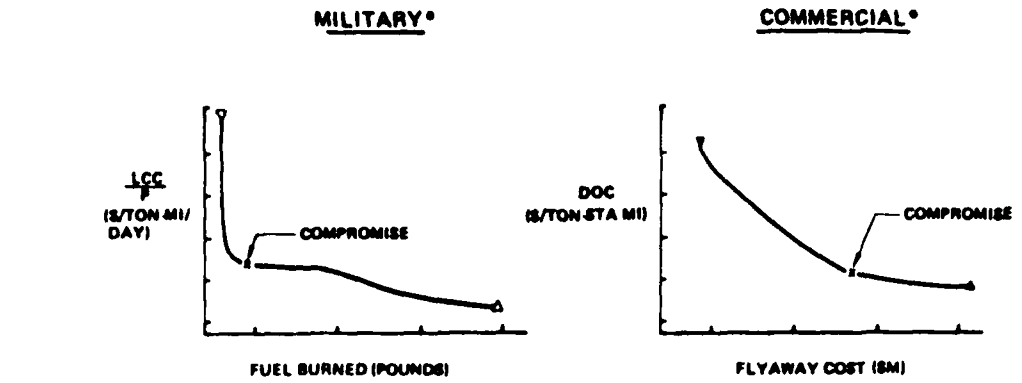
The two extremes in the group are the LCC/Productivity and fuel optimized designs. The LCC/P airplane combines the highest wing loading, thrust/weight and span loading while the minimum fuel design has the least value of these parameters. These two designs, exceeding both takeoff and cruise altitude constraints, also have the extremes in climb gradient.

Note that minimum fuel is gained at the expense of a large airframe having additional design problems, such as gust loads, taxi loads and hangar accommodations.

Figures of merit may be optimized singly, as shown on Figure 3.6.4 and as discussed in the preceding paragraphs, or they may be optimized in combination. Figure 3.6.5 illustrates combined, or compromised, figures of merit which have been used for military and commercial freighters selection, Reference 1.2.

Figure 3.6.6 illustrates the characteristics of a transition between a minimum fuel load optimum and a minimum LCC-productivity optimum. The end points of the curves represent singly optimized figure of merit airplanes. As one figure of merit is successively compromised in favor of the other, the transition is characterized. The transition line represents an infinite number of different airplanes. The discontinuities in the curves occur at study limits on design variables. Encounters occur with the lower allowable limit on t/c (0.09) and with the upper limit structural aspect ratio (15.0). A compromise design on the transition line is identified by the "x". This particular compromise is of the equal-penalty variety. It is apparent that the design and performance characteristics of a compromise can be changed substantially if other than equal penalty to the conflicting figures of merit were used as the compromise criterion.

The design options baseline airplane was selected based upon the commercial compromise design figures of merit, flyaway cost (unit production cost) and direct operating cost (DOC). Typical commercial compromise transition curves and resulting designs are illustrated in Figure 3.6.7. Some insensitivity of DOC to flyaway cost is noted until the "compromise" airplane is reached. For this part of the curve, the aircraft has wing planforms of high sweep angles, and cruise Mach numbers are high. As flyaway cost is further reduced, the wing sweep angle and the cruise Mach number are also reduced.



*Selection basis for IADS II study aircraft.

Figure 3.6.5 Compromise Design Figures-of-Merit

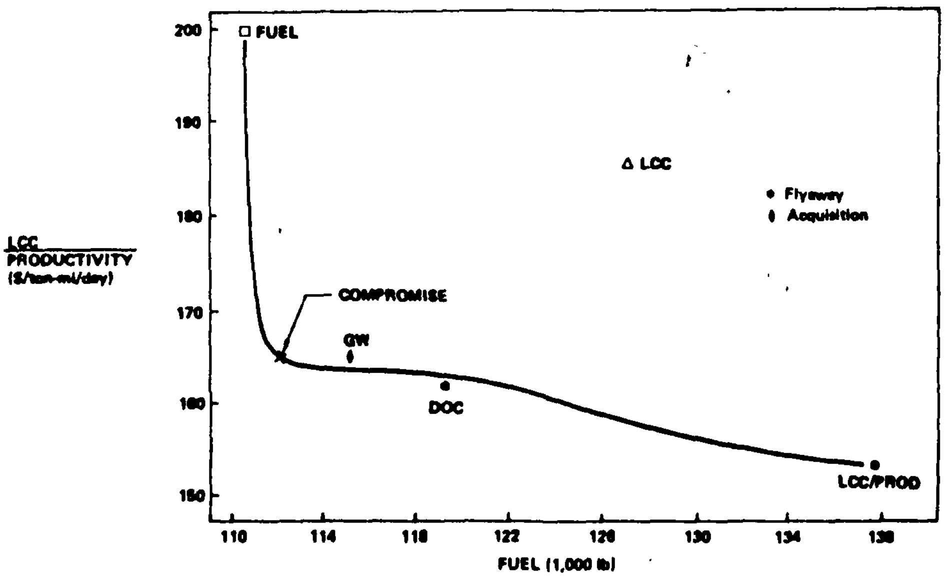


Figure 3.6.6 Compromise Design Figure-of-Merit Boundry Military Freighter

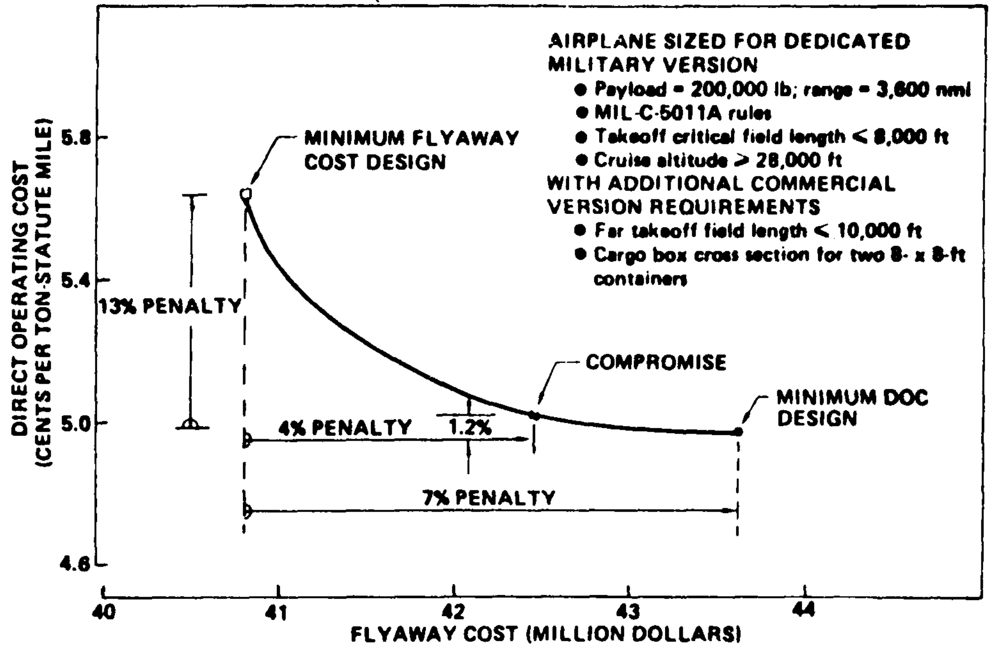


Figure 3.6.7 Compromise Figure-of-Merit Trade Boundry Commercial Freighter

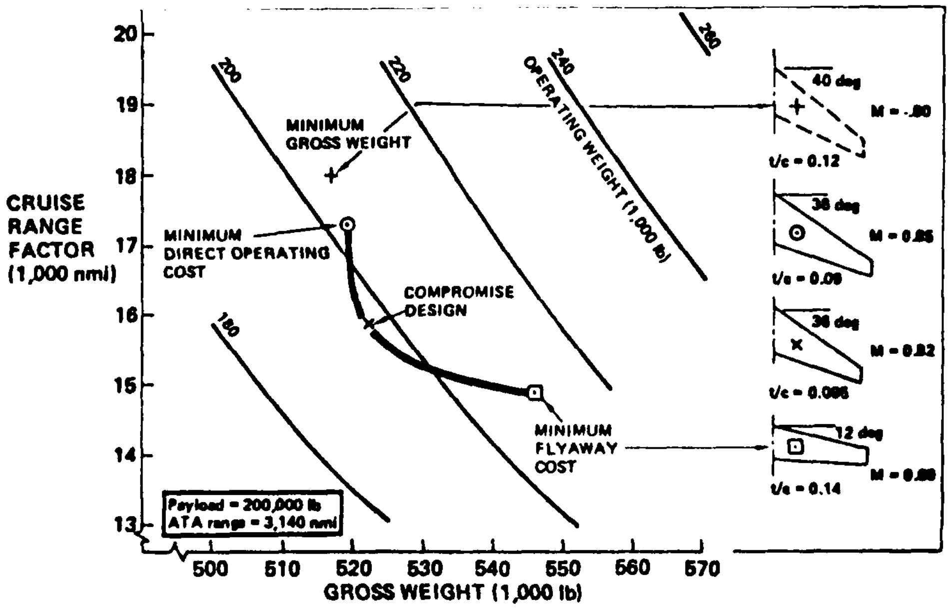


Figure 3.6.8 Commercial Freighter - Design Figures-of-Merit

The commercial compromise in terms of flyaway cost and DOC is meaningful if flyaway cost can be considered representative of price. Rather than equal penalty, an actual compromise would depend on financial conditions in the marketplace. If money is plentiful, the compromise would be hedged toward minimum DOC. If money is tight, DOC would be less important the the compromise would tend toward minimum initial investment of flyaway cost.

The compromise figure of merit trade boundaries may also be plotted in terms of the performance parameters, operating weight and range factor, versus gross weight as shown on Figures 3.6.8 (commercial) and 3.6.9 (military). The singly optimized designs are the end points of the transition curves and the compromise aircraft are again indicated by an "x". The planform variations indicate the commercial designs vary from high wing sweep angles and high cruise Mach numbers (minimum DOC) to low sweep angles and low cruise Mach numbers. The compromise design maintains a high cruise Mach number and sweep angle but not as great as the minimum DOC design.

Planform trends for the military freighter are shown on Figure 3.6.9. The most extreme planforms for the various figures of merit studied are indicated. The minimum fuel burned design has the highest aspect ratio, lowest sweep angle, and nearly the lowest cruise Mach number. The LCC/P design has the lowest aspect ratio and nearly the highest sweep angle and a high cruise Mach number. The military compromise design is nearly the same as the minimum DOC design except the wing geometry is quite conventional.

A basic engine airframe size matching diagram of thrust/weight versus wing loading for the compromise commercial freighter case is shown on Figure 3.6.10. For this depiction, the wing geometry was held constant and the mission matched gross weight determined for constant Mach number in cruise. Local optima for the figures of merit may be identified that are unconstrained. Regions of minimum gross weight and minimum DOC are very near the compromise design at 522,000 pounds gross weight and 8,000 foot takeoff field length. In addition, regions for minimum fuel burned and LCC/P are indicated. The low fuel consumption aircraft (for the fixed

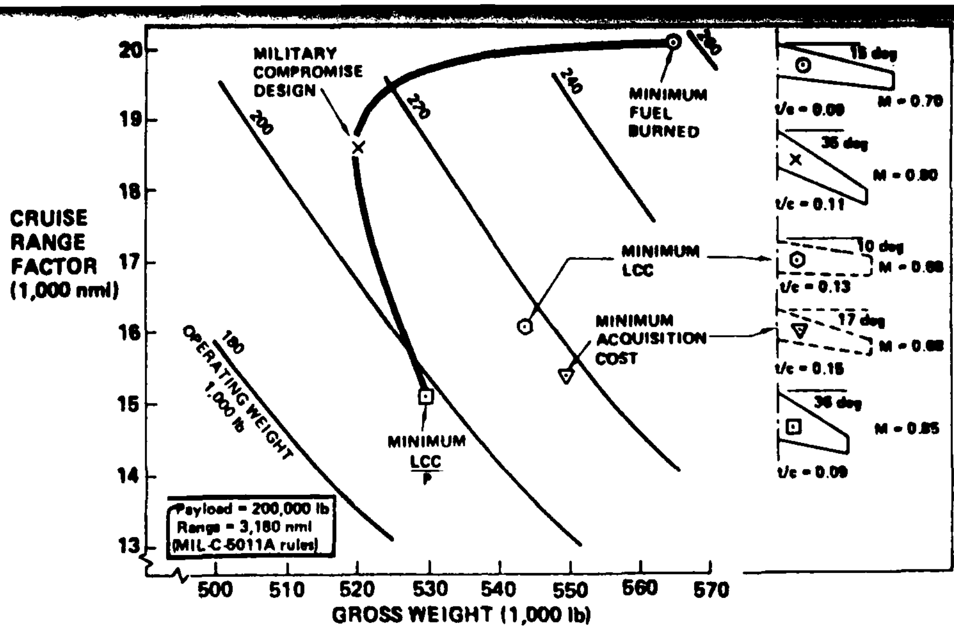


Figure 3.6.9 Military Freighter - Design Figures-of Merit

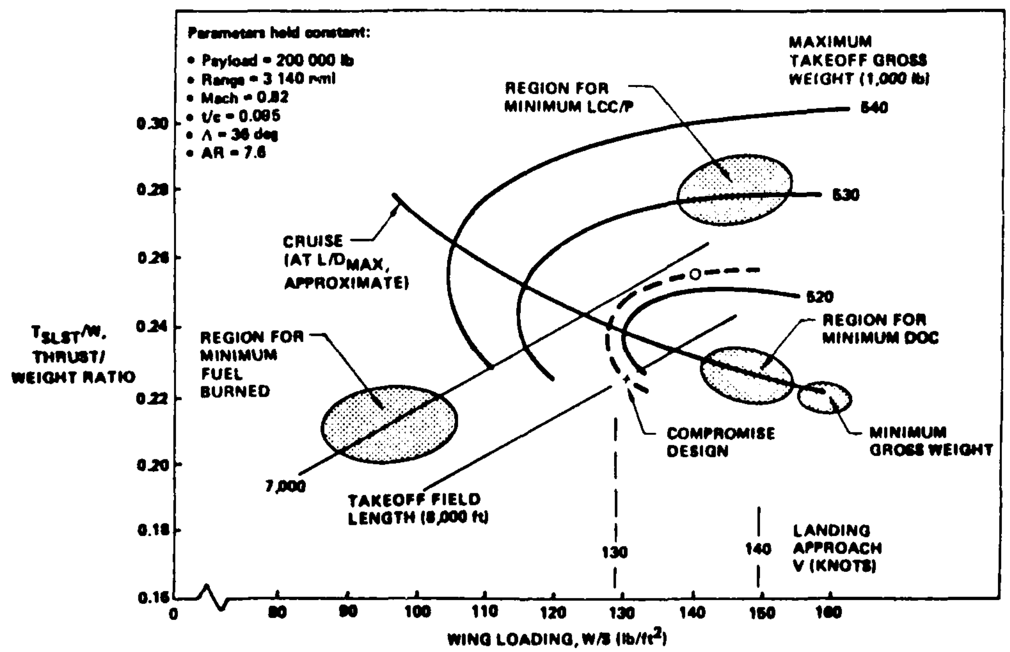


Figure 3.6.10 Engine/Airframe Matching

	Model 1044-050-200*	Compromise commercial design
Gross weight, lb	522,000	522,000
Cruise mach number	0.80	0.82
Cruise altitude, ft	36,400	31,500
Takeoff field length (military), ft	7,190	8,000
Wing loading, lb/ft^2	140	130
Thrust/weight	0.258	0.228
Aerodynamic aspect ratio	7.96	7.55
Leading edge sweep angle, deg	33	36
Mean thickness ratio	0.108	0.09
Direct operating cost penalty over minimum, %	3.9	1.2
Flyaway cost penalty over minimum, %	6.7	4.0

*Basic results from IADS II study.

Figure 3.6.11 Design Point Selection and Comparison

- A baseline commercial freighter, initially designed to include strategic military aircraft requirements as well, has been selected. This design meets both requirements with minimum penalties.

- Application of advanced technologies provides a significant gross weight reduction relative to current technology, a necessary condition for introduction of a new commercial aircraft.

- Selection procedures and rationale used, including commercial and military design figures of merit, provide confidence that the best design can be selected through detailed performance and cost trade-offs.

Figure 3.6.12 Summary - Baseline Airplane and Selection Rationale

planform) also occurs at a low wing loading and low thrust weight ratio. By contrast, the LCC/P designs optimize with large engines and small wings for the high cruise Mach number and field length requirements.

The Model 1044-050-200, Figure 3.2.1, design point characteristics are listed on Figure 3.6.11. The second column of Figure 3.6.11 is the compromise commercial design and was based upon a more recent data base. When compared with the Model -200 planform, characteristics, etc., the compromise design was judged not sufficiently different to warrant a change for purposes of the design options evaluation study.

The significant points to be made regarding the baseline airplane selection and design rationale are given on Figure 3.6.12. Careful selection of the baseline design and characteristics is important for proper evaluation of the design features as many of the options are "configuration sensitive."

4.0 DESIGN OPTION DESCRIPTIONS

4.1 Introduction

Design options were defined in this study as special features which "enhance" or increase the military capability of CRAF versions of the study baseline airplane. In the military configuration these CRAF versions must accommodate the large number of military vehicle, weapon and equipment types for which airlift capability is desired by military planners, and load/unload military payloads rapidly and efficiently without requiring special ground equipment or facilities.

Special floor panels, large cargo doors, and loading ramps are representative design options. The options were designed for installation as kits during conversion of the CRAF fleet from the commercial to the military mode in event of a national emergency requiring augmentation of the nation's organic military airlift fleet.

The design options investigated in the study are described individually in Section 4.2. In Section 4.3, specific configurations are defined for CRAF versions of the baseline airplane, each configuration incorporating a different combination of design options. The design option analyses, costs, and evaluations reported in subsequent sections were based on these configurations.

Eleven design options were studied, Figure 4.1.1. The contractor-selected options noted in this list were included in the study to provide alternate choices for comparison with the USAF-selected options. Design objectives applicable to all of the options are summarized in Figure 4.1.2. Advanced materials and design approaches consistent with those employed in the baseline airplane, were utilized in developing the design options configurations and weights. Usually, special provisions such as attach fittings and local strengthening of basic structure must be built into the CRAF airplane to accommodate the higher floor loadings associated with military service, and facilitate rapid installation of the design option kit during conversion of the airplane from the commercial to the military mode. Because this built-in scar weight reduces the CRAF airplane commercial payload capability, it was of considerable interest and is tabulated separately in the design options weight summaries of Section 5.0.

Design Option	Military Transport Feature
1. Quick-change floor panels, main battle tank capability	Reinforced floor
2. Stabilizing struts 2A. Kneeling landing gear[a]	Reduced loading height
3. Mobile ramp, air transportable 3A. Onboard front ramp, folding[a]	Loading ramp
4. Side cargo door 4A. Swing tail cargo door	Aft cargo door
5. Lowered military floor[b] 5A. Cargo pod	Increased payload envelope height
6. Passenger modules 6A. Convertible airplane[a]	Commonality—commercial passenger-military freighter

a Contractor-added option
b In lieu of folding floor option

Figure 4.1.1 Design Options - Final Selections

- Maximum simplicity
- Minimum cost
- Minimum "scar" weight—commercial mode
- Minimum installed weight—military mode
- Minimum conversion time, commercial to military
- Minimum loading time

Figure 4.1.2 General Design Objectives - Design Options

4.2 Design Option Descriptions

4.2.1 Design Option 1: Quick Change Floor Panels

The Quick Change Floor Panel Option was installed during military conversion of the Enhanced Commercial Freighter airplane. It provided the additional strength and tiedown attach points required to accommodate heavy, outsize Army vehicles, weapons and equipment including main battle tanks. Removal of the commercial cargo loading system was not required. The conversion provides two cargo lanes abreast, each 9.2 feet wide by 166 feet in length. Scar weight was 6900 lb, and total weight (less tiedown chains) was 24,200 lbs. Conversion time was estimated at 16 hours.

Installation of the quick change floor "paves" the main deck with 42 specially designed panels, 7.3 feet X 9.0 feet by 3.25 inches thick. Panel construction was graphite epoxy, with metallic inserts and appropriate wearing surfaces as necessary. Each panel consists of a high strength face sheet supported by close-spaced longitudinal beams which straddled the commercial cargo loading system rollers as shown in Figure 4.2.1. This arrangement distributed the concentrated wheel/track loads imposed by the military vehicles into the floor support structure. The quick change floor panels were secured by the commercial cargo system restraint rails and latches. Included in the floor conversion kit was a system of add-on posts and beams which reinforced the existing floor support structure, Figure 4.2.2. The backup fittings noted on the figure were built into the airplane to facilitate rapid installation of the CRAF add-on structure. Advanced materials were used for the floor strengthening components.

Figure 4.2.3. compares the cross sections of the converted Enhanced Commercial Freighter and Dedicated Military Freighter versions of the baseline airplane. Both have the same fuselage diameter. Height of the CRAF military payload envelope was decreased by 29 inches, of which only four inches were attributable to the quick change floor panels. The CRAF military payload envelope shown provides significant outsize capability, accommodating over 90% by weight of US Army Combat Division vehicles, weapons and equipment.

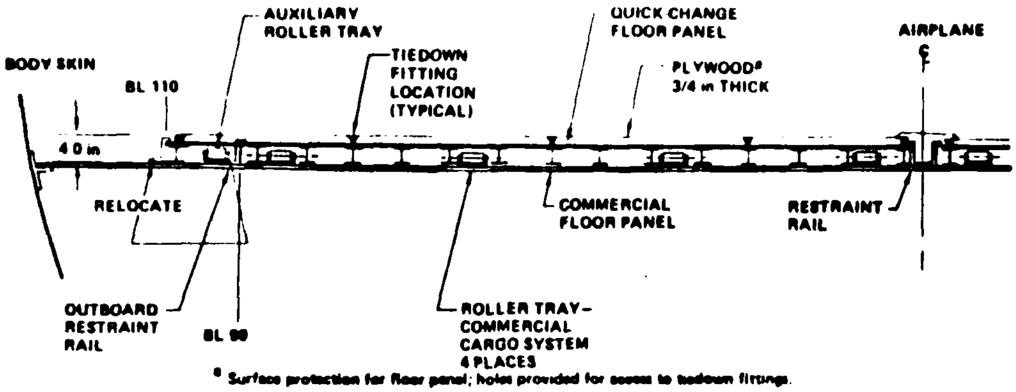


Figure 4.2.1 Quick - Change Floor Panels

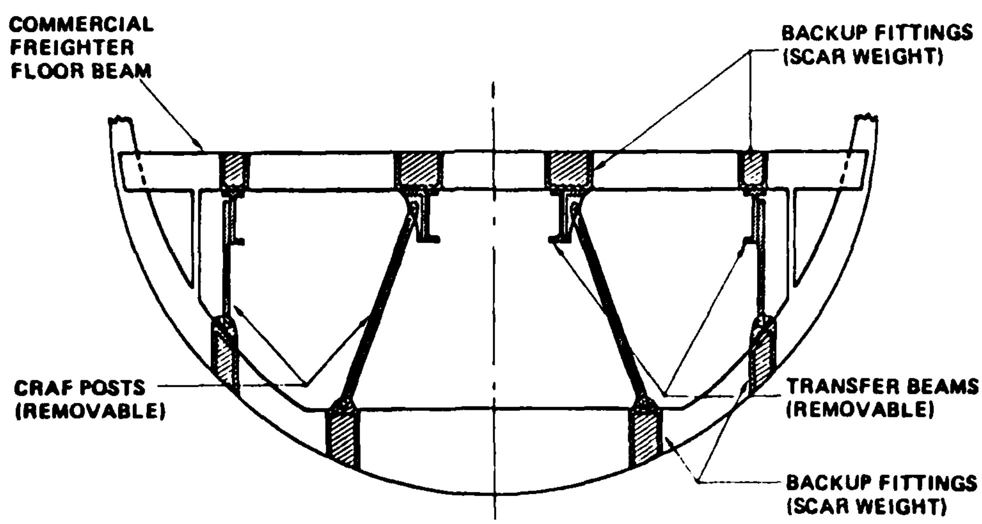


Figure 4.2.2 Strengthening Concept - Commercial Freighter Floor

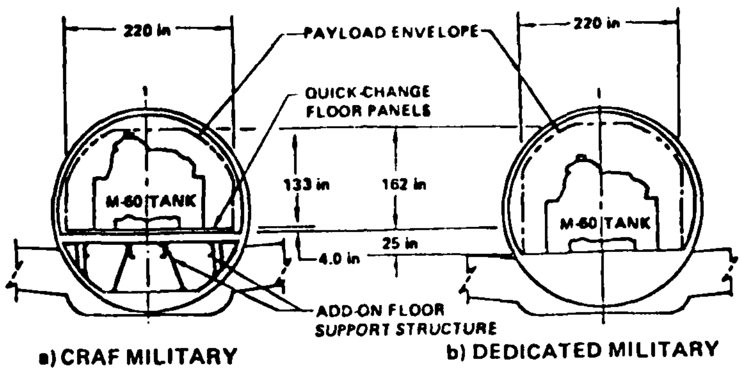


Figure 4.2.3 Cross Section Comparison - CRAF vs Dedicated Military

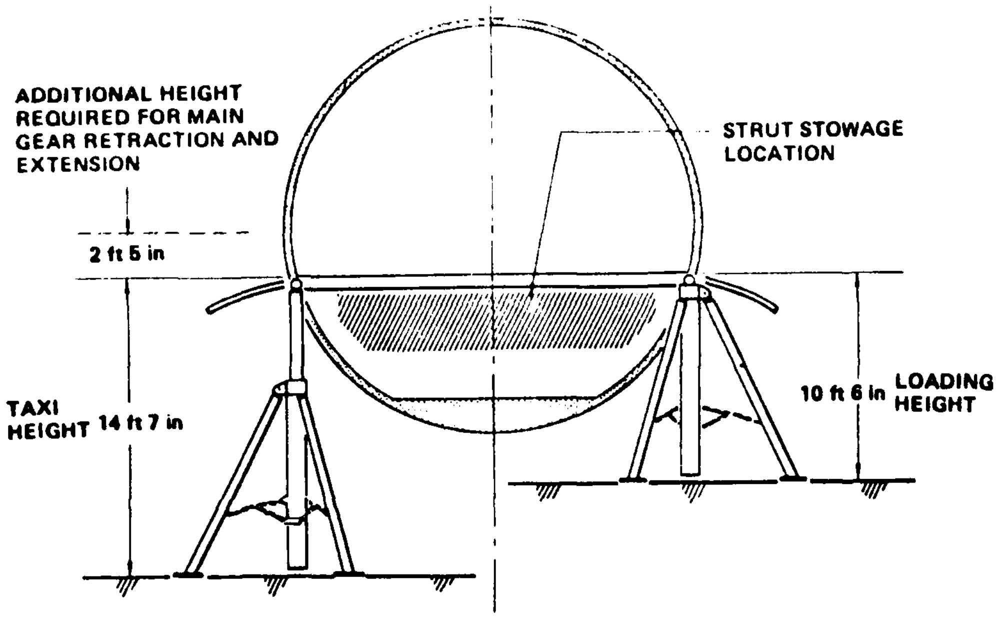


Figure 4.2.4 Stabilizing Struts - Concept and Floor Height Reduction

4.2.2 Design Option 2: Stabilizing Struts (Onboard Jacking System)

The stabilizing strut option was an onboard jacking system which reduced airplane fuselage height above the ground to facilitate cargo loading/unloading operations. The system consisted of: 1) two hydraulic jacks per side which stow in the fuselage lower lobe near the landing gear wheel wells; 2) deployment mechanisms and doors in the fuselage pressure wall; 3) an independent 3000 psi hydraulic system powered by the airplane APU or ground power source; 4) a control system with synchronizing and fail-safe provisions. As shown in Figure 4.2.4, the stabilizing strut system reduced the cargo floor height of the CRAF freighter from 14.6 to 10.5 feet, measured at the main landing gear station. Strut deployment, landing gear retraction and airplane lowering require about 20 minutes. Equal time was required to reverse this sequence and return the airplane to the taxi height condition. Installation of the stabilizing strut system kit during CRAF freighter conversion from the commercial to the military mode was 16 hours. The quick change floor option can be installed during the same period with proper time phasing of the conversion crews. System scar weight is 2,200 lb, and total installed weight in the military mode approximately 14,600 lb.

The stowage and deployment arrangements for the stabilizing struts are indicated in Figure 4.2.5. Guide rollers, tracks, hydraulic system and control elements, etc., are omitted for clarity. Strut longitudinal locations are illustrated in Figure 4.2.6.

The stabilizing struts were constructed of high strength 4340 M steel. The struts, deployment mechanism and guide rails were removable. Permanent additions to the airplane to accommodate the stabilizing struts were jackpoint fittings, load carry-through structure, attachments for support rails, pressure doors, door actuation and fixed controls.

4.2.3 Design Option 2A: Kneeling Landing Gear

Kneeling landing gear was included in the Design Options Study as an alternative to the stabilizing strut option. Kneeling provides a

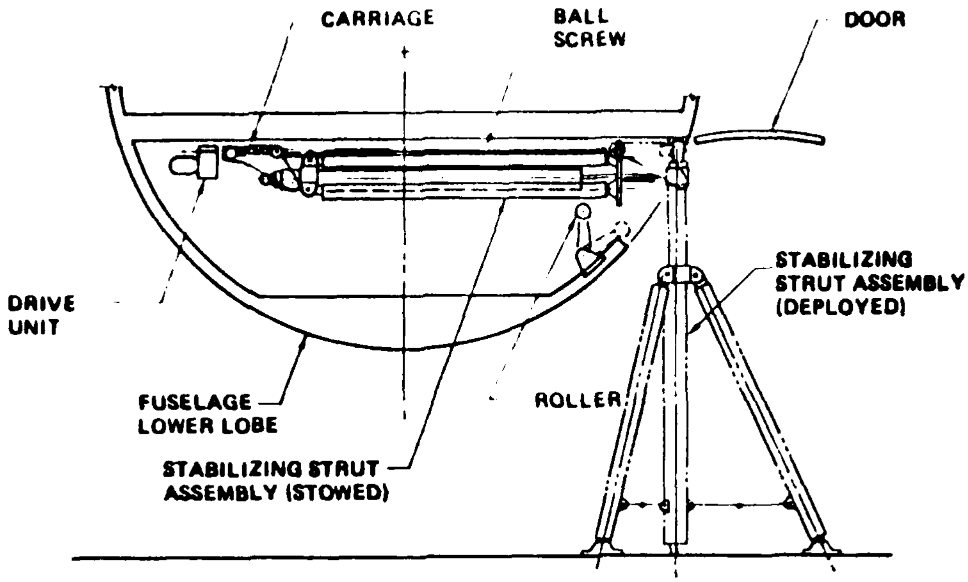


Figure 4.2.5 Stabilizing Struts - Installation and Deployment

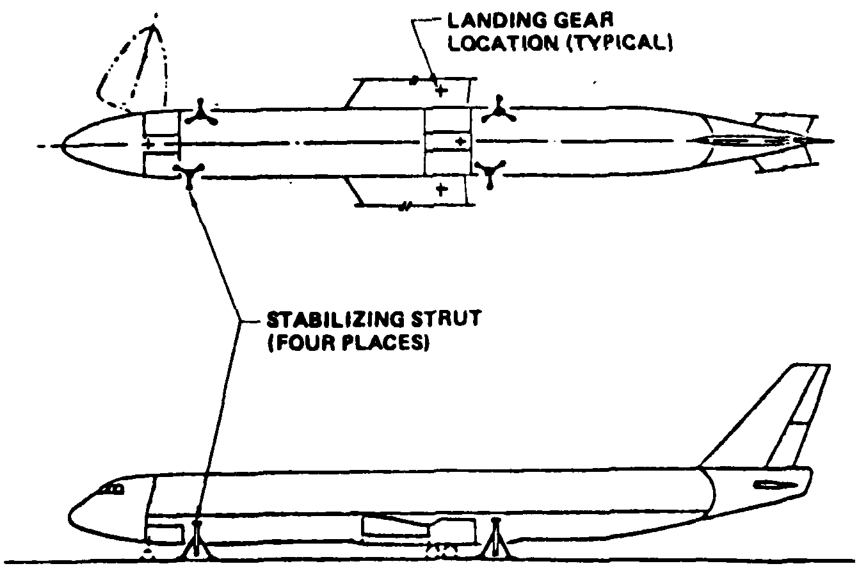
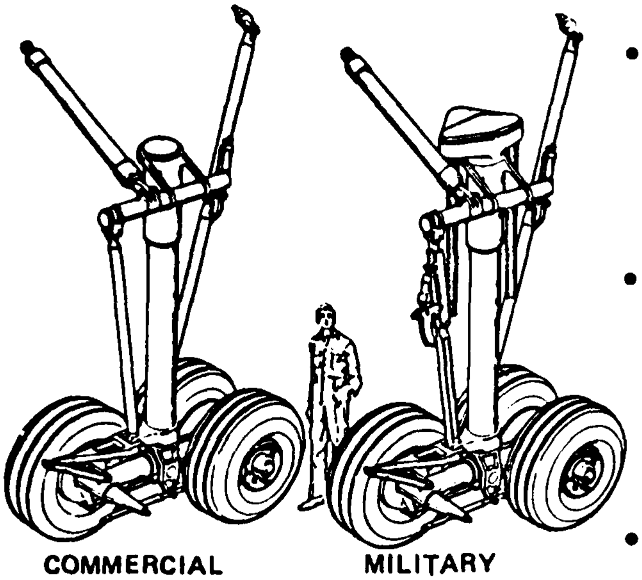


Figure 4.2.6 Stabilizing Struts - Locations on Airplane



- Conversion kit
  - New trunnion and socket
  - Ballscrews and motor
  - Folding drag brace
  - Modified hydraulics
  - Kit weight = 2,600 lb (two gears)
- Commonality
  - Wheels, brakes, tires
  - Truck and axles
  - Piston
  - Outer cylinder
  - Side brace
  - Torsion links
  - Retraction
- Load classification number
  - 70 LCG/LCN method

Figure 4.2.7 Kneeling Landing Gear

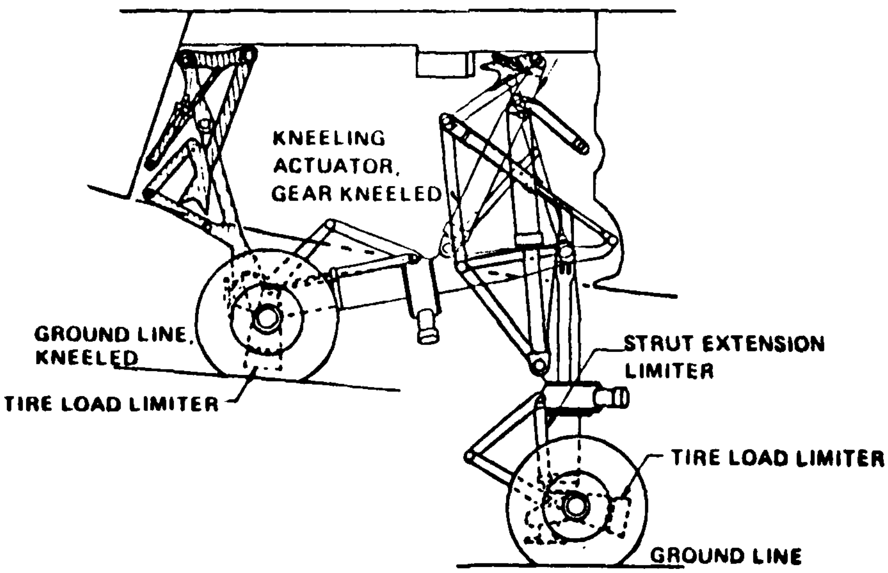


Figure 4.2.8 Kneeling Nose Gear

comparable reduction in cargo floor loading height with a significant reduction in weight:

Option	Scar Weight (lb)	Total Weight (lb)
Stabilizing Struts	2,200	14,600
Kneeling Landing Gear	290	3,190

The kneeling option's principal disadvantage is its effect on CRAF airplane conversion time - 40 hours vs 16 hours for struts. Other comparisons and overall results of the evaluations are presented in Section 7.0.

The concept for adding kneeling capability on the outboard main gear of the Enhanced Commercial Freighter is summarized in Figure 4.2.7. Principal components involved in the conversion were: 1) a new trunnion and fitting on the upper end of the oleo outer cylinder; 2) additional of two ballscrews, drive motor, and connections to a hydraulic or pneumatic power source; 3) a new, folding drag brace. Doors in the upper surface of the wing secondary structure are required to allow the oleo to protrude through this region as the airplane is lowered. The center main gear required little change since it was retracted as the first step in the kneeling cycle.

Nose gear kneeling was provided by adding components which enable partial retraction of the gear as shown in Figure 4.2.8. Overloading of the nose gear tires while heavy payloads are crossing the nose door sill was prevented by the tire load limiter. This device bears on the ground when the nose gear tires deflect beyond safe limits, transmitting the load through a linkage system to the body structure above the nosewheels.

4.2.4 Design Option 3: Mobile Ramp

The air transportable mobile ramp shown in Figure 4.2.9 is designed primarily for drive-on loading/unloading of military logistics transports such as the Design Options Enhanced Commercial Freighter. Heavy outsize vehicles including main battle tanks can be accommodated. Slope of the ramp as illustrated is about 13.5 degrees when connected to the nose door

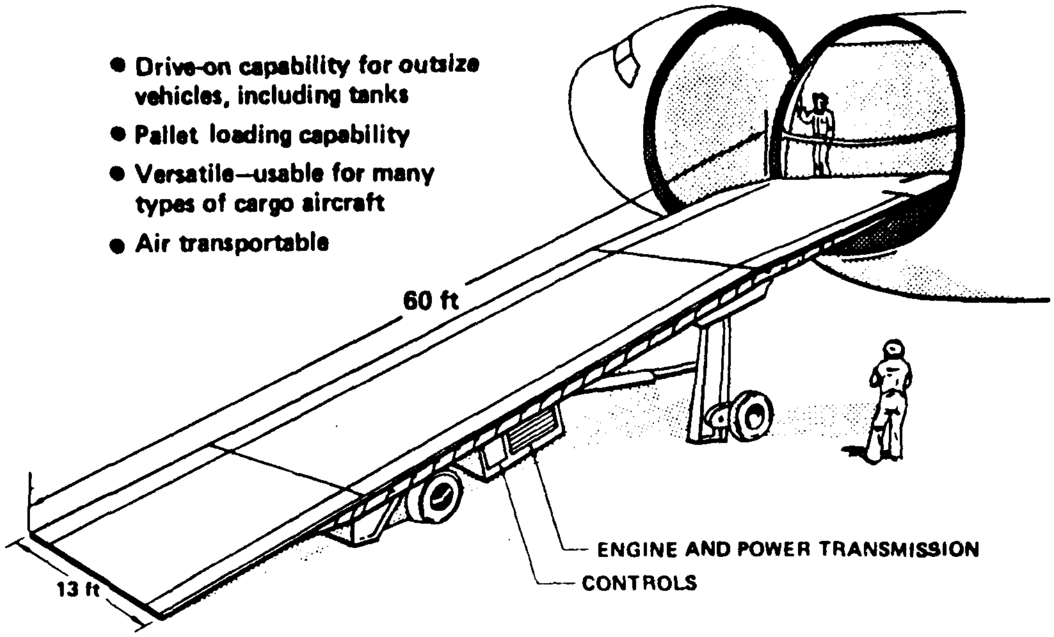


Figure 4.2.9 Mobile Ramp - Deployed Configuration

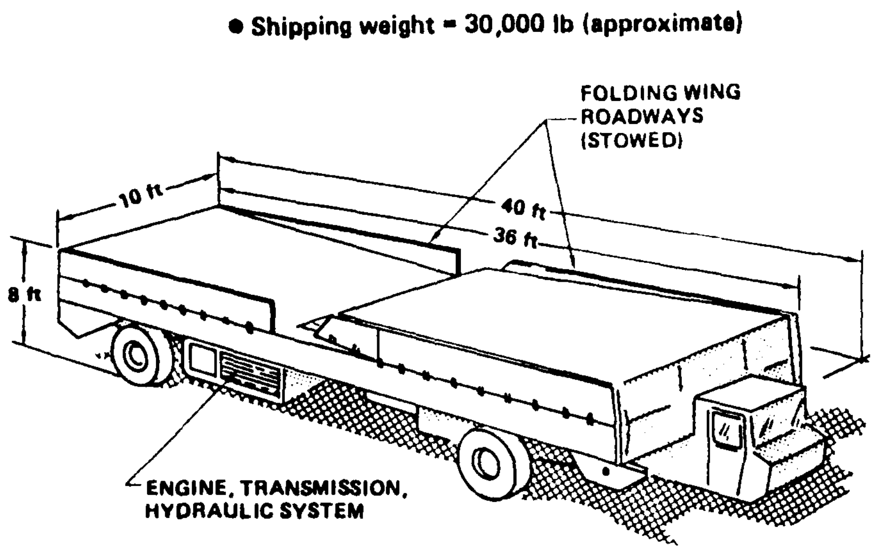


Figure 4.2.10 Mobile Ramp - Air Transport Configuration

sill 14 ft static height above ground. Palletized cargo can be loaded/unloaded with the addition of quick-deployable roller trays and a built-in powered shuttle. The mobile ramp engine, transmission, hydraulic power supply, and controls provide self-contained ground mobility, ramp leaf deployment, and height adjustment capabilities.

Figure 4.2.10 shows the mobile ramp in its air transport configuration. The compact envelope of the unit permits air shipment in C-141 or larger military transports. Shipping weight is approximately 30,000 lb. A deployment time objective of 30-60 minutes from shipping to work-ready configuration was postulated.

The air transportable ramp described in this section was based on a conceptual design developed by the Pacific Car and Foundry Company (PACCAR), Renton, Washington in conjunction with Boeing. It utilizes folding aluminum bridge technology developed for the U.S.Army by PACCAR.

The mobile ramp imposed few requirements for special fittings or provisions on the airplane it serves. Hook type fittings on the door sill to maintain ramp/airplane alignment are all that was necessary, and they need not differ from those provided for commercial operations.

Delivery and deployment of the first mobile ramp could pose an operational problem if only CRAF freighters were employed for an airlift deployment. At least two solutions appear valid: 1) transport the number one mobile ramp in a dedicated military freighter equipped with an onboard ramp; 2) preposition mobile ramps at major airbases.

The mobile ramp offers a number of advantages. It can serve a wide variety of aircraft types, including 747 and DC-10 commercial freighters requisitioned for military service, and serve front, side and rear cargo doors. On deployments requiring multiple flights to a given destination, ramps need be carried on only a few of the initial flights. Fleet airlift

productivity (tons per day) is thereby increased, compared to similar aircraft equipped with onboard ramps.

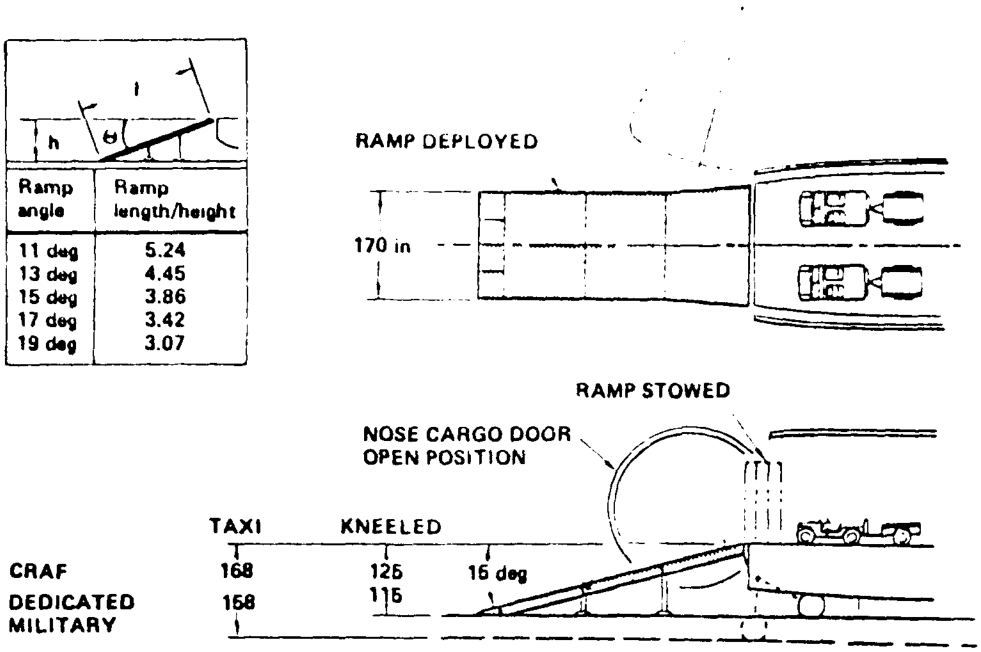
For these reasons, the mobile ramp appears to merit further investigation and development in future studies.

4.2.5 Onboard Front Ramp, Folding Type

The Onboard Front Ramp, Figure 4.2.11, was an alternative to the Mobile Air Transportable Ramp described in the previous section. It provides self-contained drive-on loading/unloading provisions on every flight, avoiding the problem of assuring that a mobile ramp is available on the ground at the destination airbase. However, the onboard ramp takes up airplane payload space and weight capability on missions to bases where suitable ground based loading/unloading facilities are available. Thus a case can be made that both types of ramps should be provided within the airlift fleet.

The onboard ramp shown includes a powered extension/retraction system. Time allowed for one extension/retraction cycle is 0.20 hours. The ramp was designed to accept all wheel and track type payloads the Design Options dedicated military and enhanced commercial airplanes can accommodate, including main battle tanks. Advanced structural materials and systems technology were used. Pallet loading capability can be provided by incorporating quick change roller trays and guide rails into the ramp design. These provisions are similar to corresponding cargo system components which were integrated into the dedicated military airplane cargo floor design. A slope of 15° was used for the Onboard Ramp configuration and weights. Other slopes would affect ramp length as indicated in the table on Figure 4.2.11, with corresponding effects on ramp stowage volume and weight. The landing gear kneeling option was used in conjunction with the onboard ramp in many of the Design Options enhanced commercial airplane configurations to minimize ramp size and weight.

CRAF airplane provisions to accommodate the onboard ramp include sill reinforcement, hinge fittings, uplocks, and entension/retraction system provisions. Scar weight in the CRAF airplane was approximately 800 lb and



Ramp angle	Ramp length/height
11 deg	5.24
13 deg	4.45
15 deg	3.86
17 deg	3.42
19 deg	3.07

Figure 4.2.11 Onboard Front Ramp - Folding Type

total installed weight slightly under 4,700 lb. The conversion time estimate of 48 hours included installation of the landing gear kneeling option.

4.2.6 Rear Side Cargo Door

The Rear Side Cargo Door Option was added to the Enhanced Commercial Freighter airplane to provide drive-thru loading/unloading capability in conjunction with the nose cargo door included in the basic freighter configuration. An onboard front ramp was assumed for the nose door and a mobile air transportable ramp for the aft door in the study ground operations analysis. An extra large door compared to current commercial freighter side cargo door sizes is shown in Figure 4.2.12 to facilitate loading/unloading outsize military payloads. An aft body strut was provided to assure that airplane tip-back cannot occur when the aft cargo door is in use.

Design and weights analysis for the Rear Side Cargo Door were tasks for which a wealth of background data and experience are available from commercial freighter programs. Adjustments for incorporation of advanced materials and technology were handled in the same manner as in design of the baseline airplane.

Installed weight of the Rear Side Cargo Door is 5390 lb. All of this was considered scar weight in the analysis since few components can be deleted for weight reduction in the commercial mode. As a consequence, conversion time was taken as zero. The support strut increases total option weight by 400 lbs; 25% of this was scar weight.

4.2.7 Swing Tail Cargo Door

The Swing Tail Cargo Door, Figure 4.2.13, was an alternative to the rear side cargo door for providing drive-thru capability in the Enhanced Commercial Freighter. The Swing Tail Cargo Door location was selected at a point on the aft body where the fuselage cross-section size is comparable to that at the nose door. Hinging the aft body introduces less complication than might be expected because there are no flight control cable runs to the empennage (fly-by-wire). The weight increment for the swing tail was 5700

pounds, comparable to that for the rear side cargo door. Almost all of that weight is built into the airplane permanently. Activation of the swing tail provisions during CRAF airplane conversion for military operations would require only a few hours. Principal tasks would be installation of the tail door actuators and checking out the actuator drive and door latch systems. Loading ramp and aft body support strut requirements for this swing tail were handled as described for the side door.

Both horizontal and vertical swing concepts were considered for the tail door option. Vertical swing was selected on the basis of less interference with ground operations when the door is open. Design wind conditions are: 1) door actuation, winds to 40 knots; 2) door stationary, partial to fully opened, winds to 65 knots.

4.2.8 Lowered Military Floor

The Lowered Military Floor was substituted with ASD approval for a Phase I option selection titled, "folding floor". The purpose of the folding floor option, increased military payload height capability in the CRAF military mode, is achieved with an approach better suited to the Design Options baseline airplane by using the lowered floor concept. Investigation of folding floor concepts in the IADS-76 study, Reference 1.1, led to the conclusion that they are best suited to large, double deck aircraft. Figure 4.2.14 is an example of a commercial freighter cross-section in which the folding floor approach can be applied efficiently to enhance its CRAF military capability. The cross-section shown is approximately 30 percent larger than the Design Options baseline, and further increases might be required to accommodate the airplane wing.

The Lowered Military Floor Option applied to the Design Options Enhanced Commercial Freighter is illustrated in Figure 4.2.15. The military payload height benefit was as shown in Figure 4.2.3. Essentially, the commercial freighter floor and substructure are designed for rapid removal and replacement by a modularized, quick change version of the dedicated military airplane floor. Frame strengthening and attach fittings for both

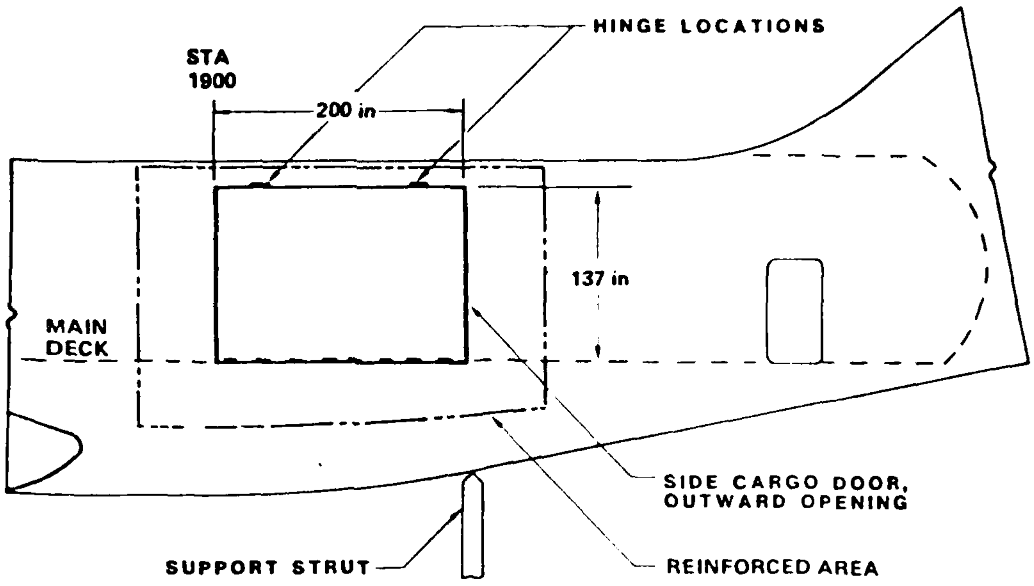


Figure 4.2.12 Rear Side Cargo Door

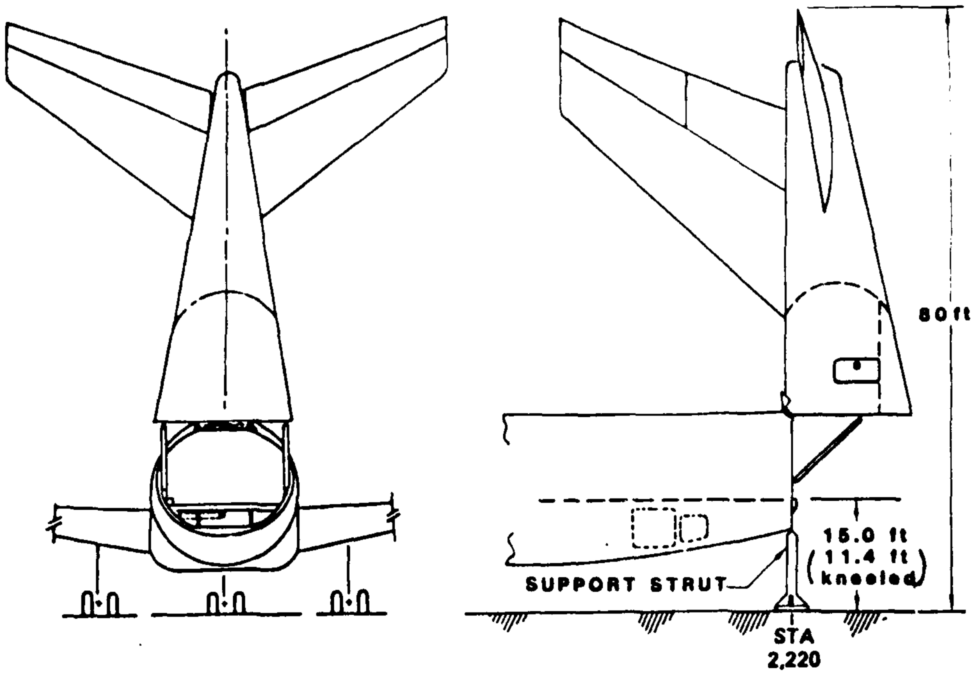


Figure 4.2.13 Swing Tail Cargo Door

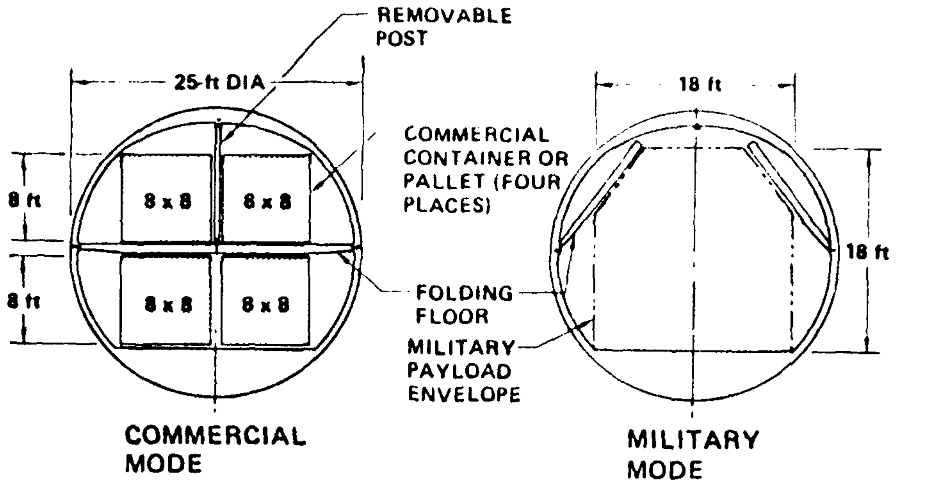


Figure 4.2.14 Folding Floor Concept

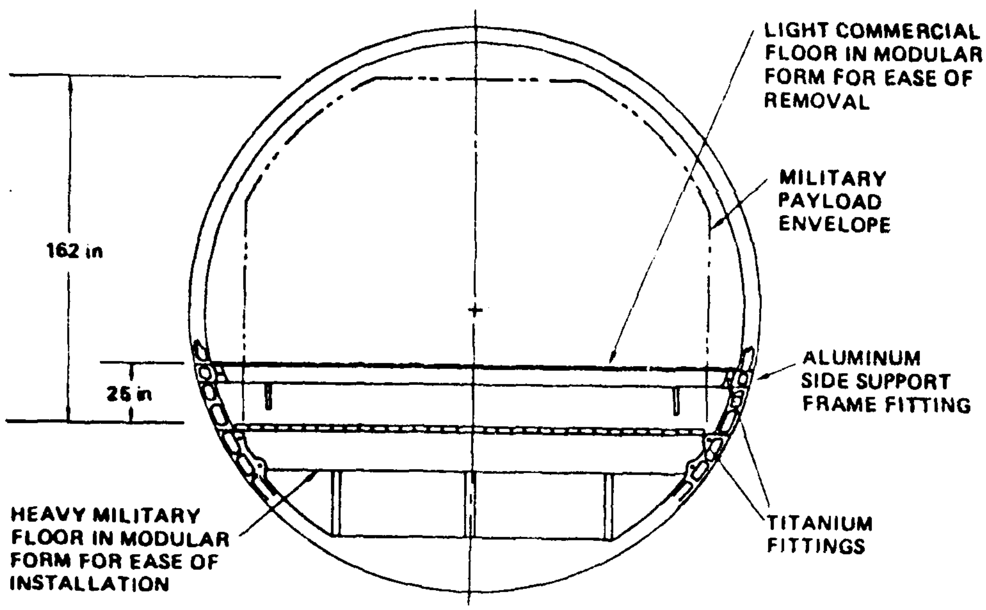


Figure 4.2.15 Lowered Military Floor Concept

floors were built into the airplane. The commercial cargo loading system was removed and replaced by a military cargo system integrated into the lowered floor as part of the floor conversion. Floor exchange and other CRAF military conversion tasks are accomplished at major depots equipped with necessary facilities, equipment and trained crews.

The increase in airplane operating weight attributable to the floor and cargo system exchange was 11,250 lb. Approximately 8400 lb of this was SCAR weight. Floor conversion time was estimated to be 93 hours under ideal conditions.

The lowered military floor was among the most ambitious of the options investigated in the Design Options Study. Future efforts should be directed toward reducing its high SCAR weight and long conversion time if development of the concept is continued.

4.2.9 Cargo Pod

The Cargo Pod Option was paired with the lowered military floor as an alternate approach to providing increased military payload height capability, compared to that available in the enhanced commercial freighter version of the Design Options baseline airplane, Figure 4.2.3(a).

The Design Options Cargo Pod concept was based on a NASA study, Reference 4.1. In this concept, outsize military payloads were airlifted during periods of national emergency in large, specially designed pods attached to the bellies of Design Options enhanced passenger airplanes. The cargo pod/carrier airplane configuration and cross section are shown in Figures 4.2.16 and 4.2.17.

The cargo pod was optimized for drive-on loading/unloading and carriage of wheel and tracked type military vehicles and equipment, including main battle tanks. Military pallets are accommodated also. The payload envelope cross section developed for the Design Options Dedicated Military Freighter airplane was adopted for the cargo pod. It satisfied the

outsize requirement, resulting in a cargo pod of appropriate size, and facilitated comparisons with the other design options. The cargo pod double arc cross section, Figure 4.2.17, minimized height of the cargo floor for loading/unloading operations and was well suited for pressurization. The cargo pod length was influenced by the following factors: 1) aerodynamic drag, stability and control, and balance considerations; 2) payload capability of the pod/airplane combination and floor loading; 3) pod nose gear/main gear separation required for satisifcatory pitch characteristics in taxi and ground roll. The aft loading door and ramp arrangement shown in Figure 4.2.16 are well suited to the configuration. A new pod mounted landing gear was required due to configuration constraints which prevented use of the three post main gear removed from the carrier airplane. Cargo pod structural materials and systems incorporate all technology advances utilized in the baseline airplane.

The cargo pod carrier airplane was an enhanced version of the dedicated commercial passenger baseline model, described in Section 3.0. Modifications required to adapt it for use as the carrier included: 1) lower lobe strengthening and built-in fittings for cargo pod attachment and fairing 2) horizontal stabilizer provisions for addition of tip fins 3) airplane system provisions for connection to cargo pod systems. These changes increased airplane operating weight in the commercial mode by 5100 pounds.

During the CRAF conversion process, the carrier airplane would be stripped of all readily removable passenger systems and components for minimum weight in the military mode. Deleted items would include seats, galleys, lavatories, carpets, interior trim, entertainment and emergency systems. The airplane landing gear was also removed.

The carrier airplane and cargo pod were connected by a series of links and fittings, covered by a non-structural fairing. Special facilities were required to support the airplane and adjust the relative positions of pod and airplane during the joining operation. Estimated conversion time was 58 hours. This exceeded the Design Options conversion target of 48 hours, but was 1 1/2 days less than the estimate for the lowered floor.

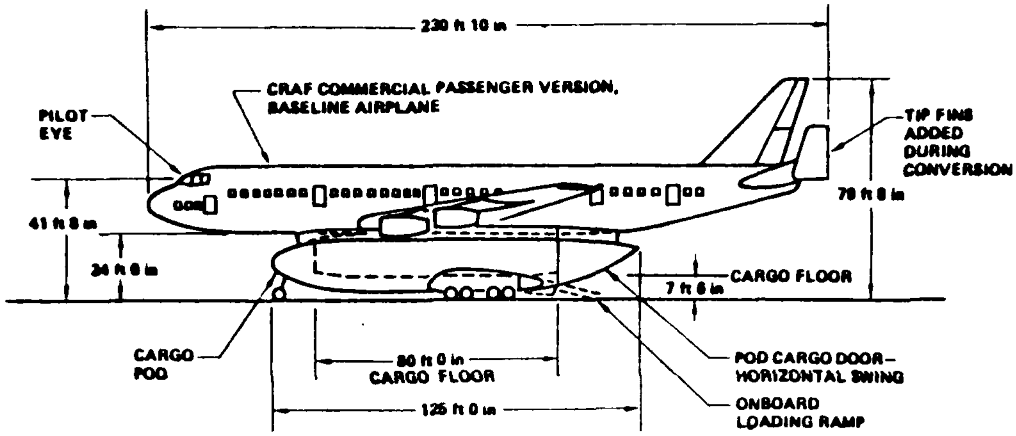


Figure 4.2.16 Cargo Pod Concept

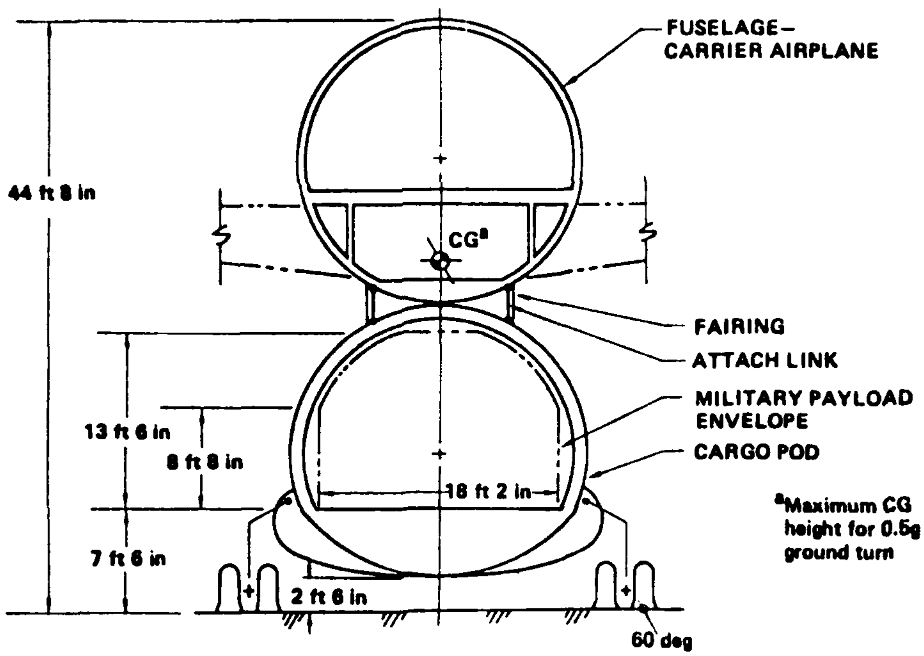


Figure 4.2.17 Cargo Pod Concept - Cross Section

The cargo pod concept offered two significant advantages compared to the lowered military floor option:

1) CRAF commercial passenger aircraft would be utilized instead of commercial freighters. Availability would be improved since airline operations require many more passenger airplanes than freighters.

2) The cargo pod offered more latitude for providing increased payload height capability than a CRAF modification of an airplane fuselage. This advantage stemmed from the fact that the cargo pod was a new, "bolt-on" design.

However, performance and productivity of the cargo pod/carrier airplane combination were degraded relative to other design option airplanes due to higher drag and operating weight. If development of the cargo pod concept is continued, basic technical areas of concern such as stability and control, pilot acceptance, and maintainability must be investigated.

4.2.10 Passenger Modules

The passenger module option was one approach for developing an enhanced commercial airplane which converts from commercial passenger service to a military freighter configuration. A modified version of the Design Option dedicated military freighter described in Section 3.3 was utilized. In the military mode it provided all of the dedicated military airplane features, including the high payload envelope, high strength drive-on floor with built-in cargo loading system, onboard ramp, and landing gear kneeling. In the commercial mode, airline passengers were seated in enclosed "passenger modules" resembling bus bodies, located in the aircraft cargo compartment.

The transportation system concept postulated for the passenger module option is outlined in Figure 4.2.18. Airline passengers board the modules at downtown airline terminals. The modules travel to the airport on semi-trailer type ground transporters. They travel directly to the

airplane, where special loading facilities transfer the modules, with passengers aboard, into the airplane. The airplane cargo loading system conveys the modules to their assigned locations in the cargo compartment and locks them in place, ready for takeoff. Galley and lavatory facilities in the ends of the airplane provide the customary in-flight services. After landing, the passenger modules are transferred to ground transporters and driven to downtown terminals in the destination city.

The passenger module is shown in more detail in Figure 4.2.19. It was sized to permit travel on city streets and highways. Seating capacity was 44 all tourist or 28 all first class, and mixed class arrangements can be accommodated. Seats, aisles and spacing conform to 707/727 standards. Single aisle arrangements were used, with doors located in both ends of the module. Interior decor, lighting and environment were comparable to that provided in contemporary airliners. Module design and materials utilize all technology advances employed in the baseline airplane.

The passenger module CRAF airplane was the dedicated military model with the following modifications 1) passenger escape doors per FAA rules in the fuselage sides, 2) increased electrical capacity,3) commercial passenger quality environmental control including soundproofing, 4) provisions for quick-change galleys, lavatories and passenger baggage system, 5) power drive units located in the floor for rapid loading/unloading of passenger modules and military pallets. CRAF type fixed length landing gear were supplied on the airline airplane to minimize weight and cost in the commercial mode and add-on kneeling was installed during airplane conversion. Onboard loading ramp provisions were also installed. Figure 4.2.20 shows the airplane interior arrangement with eight passenger modules in place. In this configuration, passenger capacity for the airplane was 328 mixed class or 352 all tourist.

In the military mode, the passenger module airplane provides 98 percent of the payload capability of the Dedicated Military Freighter, plus short conversion time - only one day. In the commercial mode, the comparison was not as favorable. The airplane operating weight in the CRAF passenger

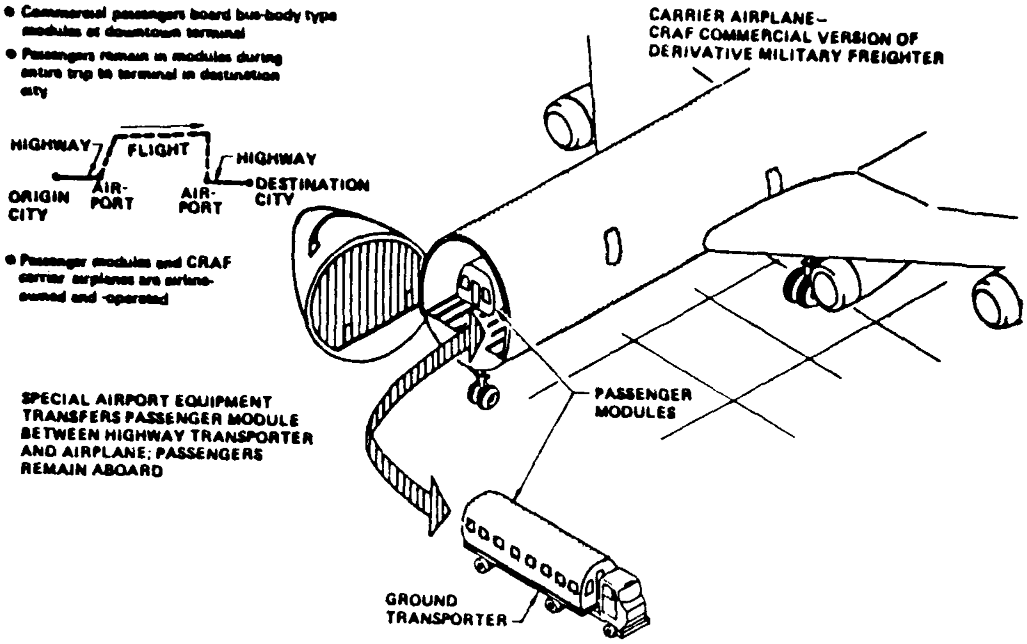


Figure 4.2.18 Passenger Modules Concept

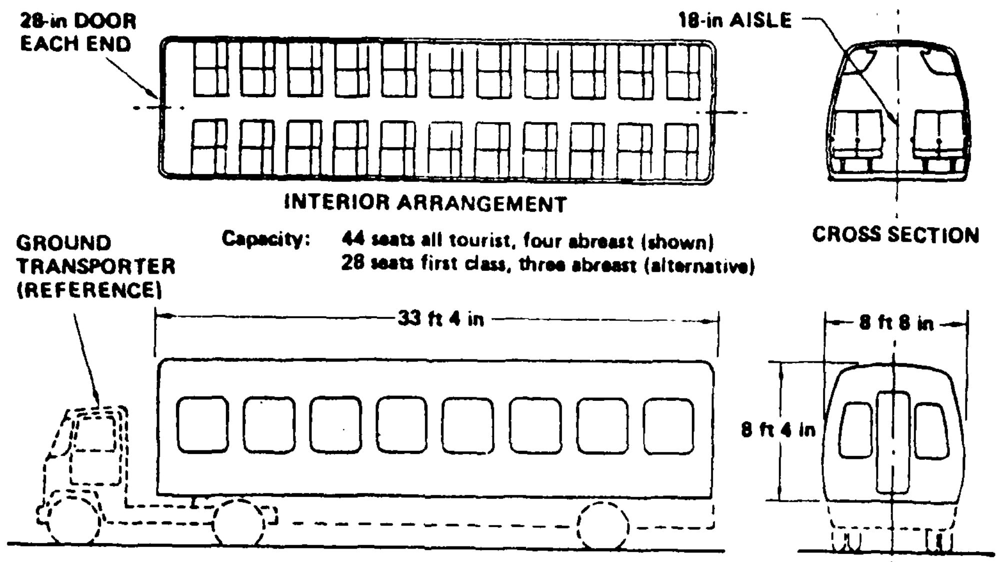


Figure 4.2.19 Passenger Module Arrangement

mode was 41,600 lb greater and passenger seating capacity was less than 80 percent of the capacity of a Dedicated Commercial Passenger model. There was little potential for significant improvement in commercial operating weight or passenger seating capacity of the passenger module option as postulated, due to inherent weight and geometric characteristics of the module/airplane system.

4.2.11 Convertible Airplane

The convertible airplane option was an alternative to the passenger module concept for providing military freighter capability in a commercial passenger airplane. Convertible passenger/freighter models of Boeing and Douglas commercial transports have been purchased and operated by the airlines since the early 1960's. Thus, the approaches, technology, and data for commercial passenger/commercial freighter convertibility are in hand. The Design Options Study has generated approaches and data for providing both commercial and military freighter convertibility. These two conversion capabilities are combined in the convertible airplane option to achieve the Enhanced Commercial Passenger objective. Figure 4.2.21 illustrates these relationships.

The Design Options convertible airplane incorporated features and provisions for quick conversion among the following configurations and modes of operation: commercial passenger/commercial freighter/military freighter. The airplane was based on the Design Options dedicated commercial passenger and freighter models described in Section 3.3, with provisions for installation of design options selected from Section 4.2 during conversion to the military mode. Principal characteristics, features and provisions combined in the convertible airplane were:

a basic configuration the same as Design Options baseline airplane, with a high floor location in fuselage, and main deck and lower lobe payload compartments; a freighter type hinged nose with passenger doors and

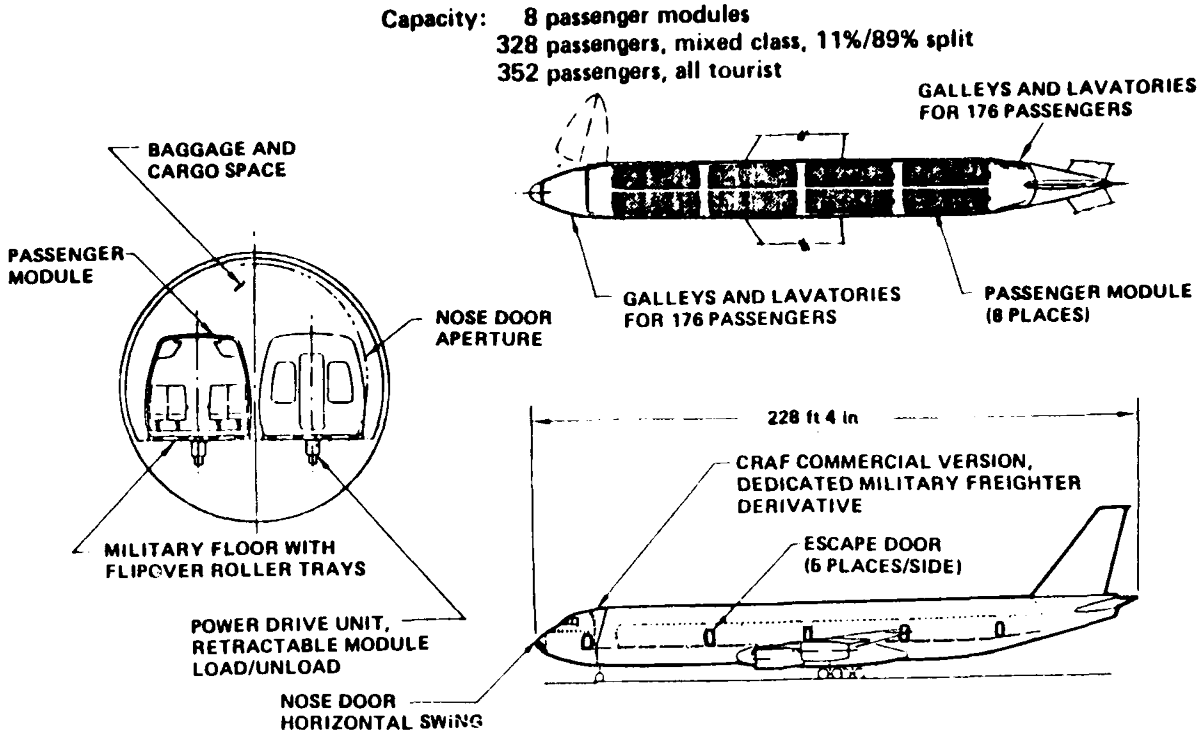


Figure 4.2.20 Passenger Module and Carrier Airplane

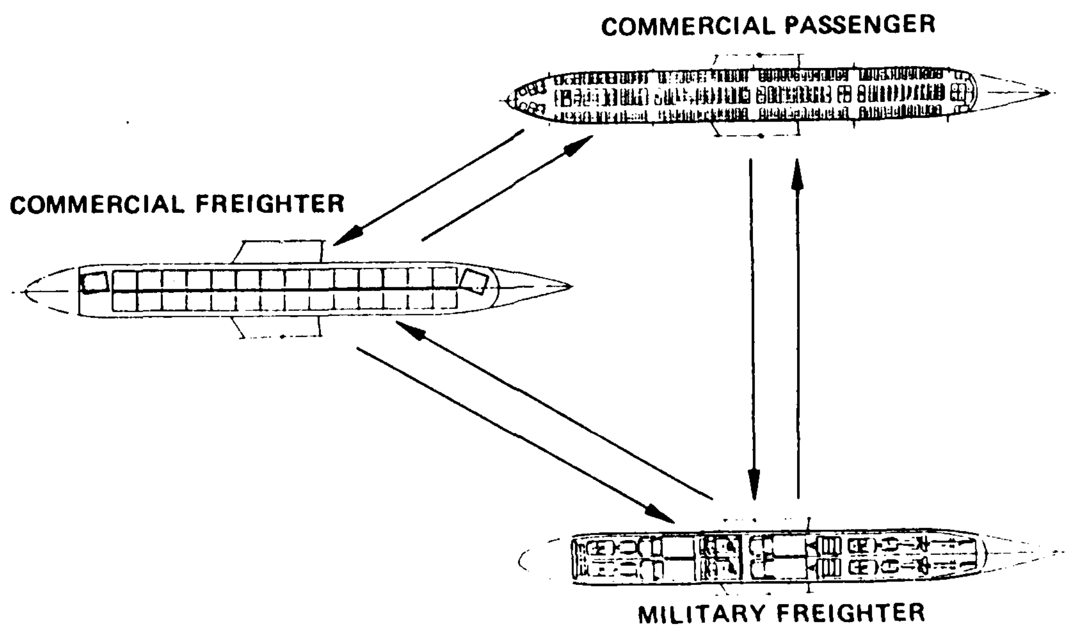


Figure 4.2.21 CRAF Convertible Airplane Concept

windows; commercial freighter floor with seat tracks; a passenger interior arrangement similar to the dedicated version, with modularized seats, galleys, lavatories, etc. equipped for quick change attachment to seat tracks and service connections, and modularized overhead passenger storage units, dropped ceilings, side trim panels equipped with quick change attachments; a commercial freighter cargo loading/restraint system equipped for quick change attachment to main deck; LD-3 containers and quick change loading system in lower lobe provided in passenger and commercial freighter modes; and provisions built in for following design options; including quick change floor panels, onboard front ramp, and a kneeling landing gear.

Removable passenger accommodation components are shown on Figure 4.2.22, and the commercial passenger/military freighter conversion process was summarized on Figure 4.2.23.

Operating weight and seating capacity of the convertible airplane in the commercial passenger mode were more favorable than those of the passenger module airplane.

Airplane	Operating Weight (lb)	Passenger Capacity Mixed Class
Convertible	271,925	423
Passenger Module	295,701	328
Dedicated	254,117	425

Military capability of the convertible airplane at 202,400 lb was less than that of the passenger module option by about 14 percent. Conversion time was two days when the onboard ramp and kneeling gear options were installed, or one day if they are omitted and the mobile ramp used for military loading/unloading operations.

4.3 Configuration Definition - Design Option Study Airplanes

The approach described in Section 2.0 for evaluation of the design options required that CRAF enhanced commercial versions of the study baseline airplane be developed

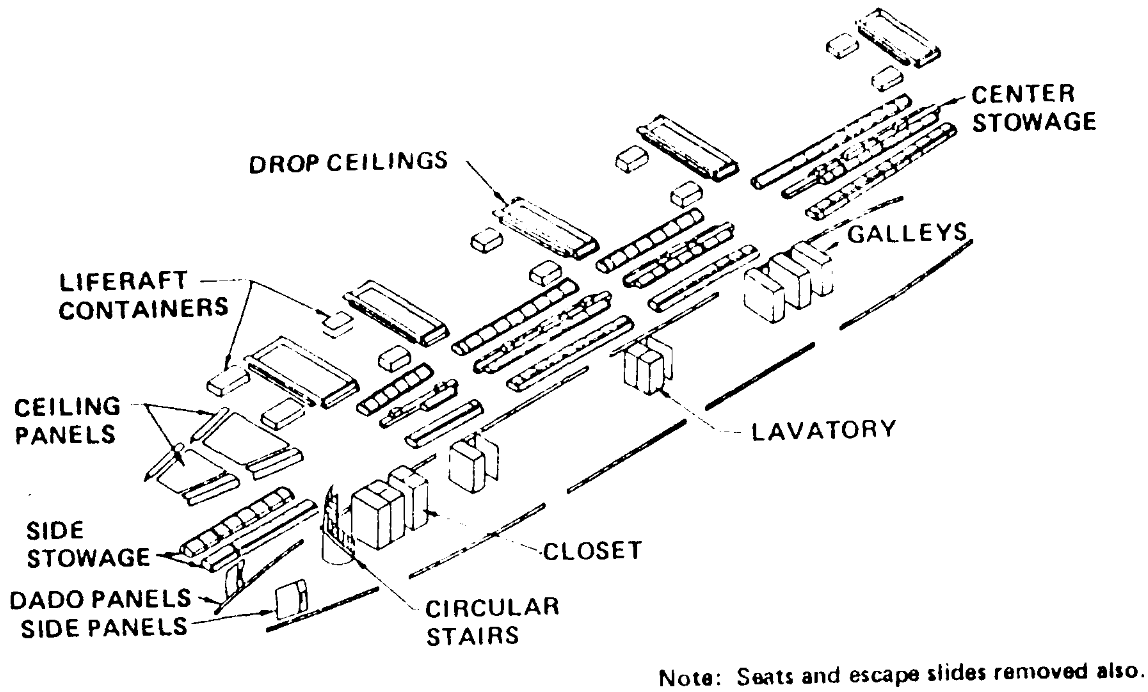


Figure 4.2.22 Passenger Convertible Components

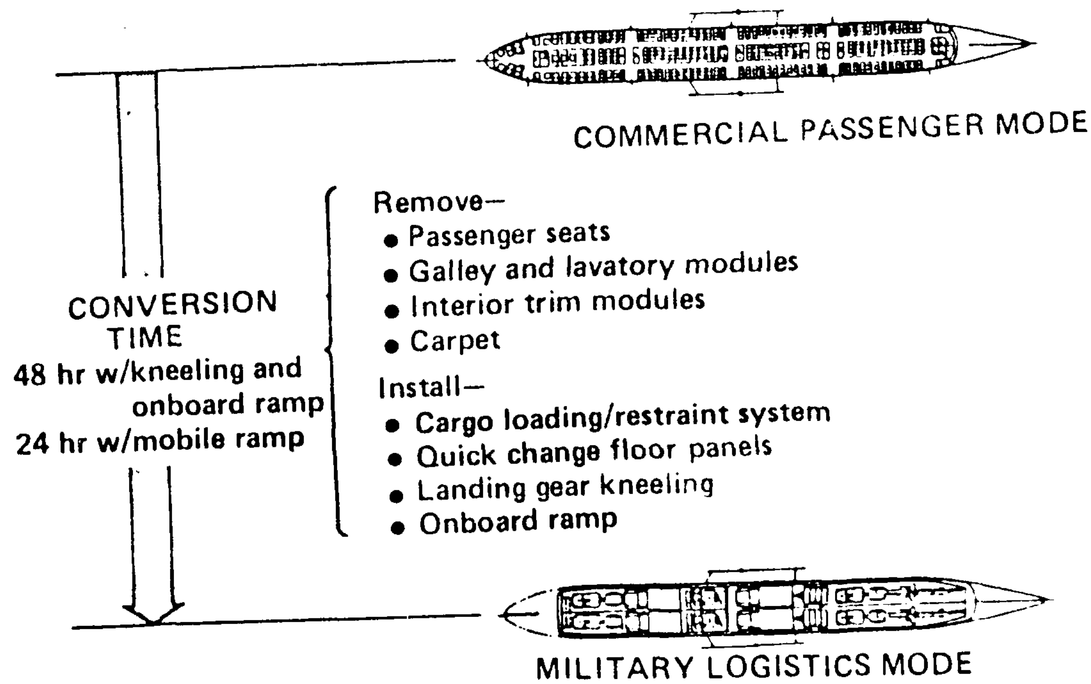


Figure 4.2.23 Principal Conversion Tasks - Commercial Passenger/Military Logistics Mode

incorporating various combinations of the Design Options. Configuration definitions for the dedicated commercial and dedicated military versions were also required. These configurations are defined and described in this section.

4.3.1 CRAF Airplanes Incorporating Design Options

The design-option-equipped CRAF enhanced commercial versions of the baseline airplane postulated for the study are identified in Figure 4.3.1. There is a column in the figure for each of these option-equipped airplanes; the airplanes are characterized and "named" by a "primary" design option incorporated in the configuration (box at top of each column). The basic military features listed in the left hand column of the figure are required in the CRAF airplanes to enable operation as outsize-capable military transports. Specific selections to provide these features are listed in Figure 4.3.1 for each configuration, utilizing design options from Section 4.2 wherever possible.

Comparing the military feature selections in successive columns of Figure 4.3.1, a general trend toward increased provisions for efficient loading/unloading operations is apparent. Also, configurations using alternate approaches for providing/improving a particular feature or capability are paired in adjacent columns (i.e., - stabilizing struts vs kneeling gear for reducing cargo floor loading height). Comparison of analysis results and data for the alternate approaches adds depth to the design options evaluations.

In Figure 4.3.1, column 1, the quick change floor panel airplane was a minimum-change CRAF enhanced configuration adding only that option for the military mode. The mobile ramp was utilized for loading/unloading operations. The airplanes of columns 2 and 2A provided alternate approaches for reducing cargo floor height to facilitate cargo loading/unloading operations. These airplanes retained the quick change floor and mobile ramp employed in Airplane 1. In the same vein, Airplanes 3 and 3A compare onboard versus mobile ramps, retaining options from the previous comparison, and 4 versus 4A compares side opening versus swing

tail aft cargo doors. Airplanes 5 and 5A differ widely in their approaches for providing a taller payload envelope than was available in the prior configurations, and 6 versus 6A compare totally different concepts for quick change capability from commercial passenger to military freighter configurations.

4.3.2 Configuration Definition - Design Options Study Airplanes

Configuration definition data are summarized in Figure 4.3.2 for all of the baseline airplane versions - dedicated and CRAF enhanced - involved in the design option evaluation studies, Section 7.0. In combination with necessary layouts, descriptions and supporting data, these definitions provided the basis for generating the airplane and military conversion kit weights, costs, conversion times and operational characteristics.

A total of 26 configurations are defined in Figure 4.3.2. The format of Figure 4.3.1 was retained, with a column for each configuration listing features and systems incorporated. CRAF enhanced airplane names and column sequence are carried over from Figure 4.3.1 for continuity.

Weight summaries for the Figure 4.3.1 study airplane configurations are provided on Figure 5.4.7. , Section 5.0. Again, the same column sequence and headings are utilized to facilitate data correlation between the study airplane configurations and weights.

Model 1044-050-	-204	-210	-208	-216	-212
Military freighter feature / Primary design option incorporated	1 Quick change floor panels, full capability	2 Stabilizing struts (onboard jacking system)	2A Kneeling landing gear	3 Mobile ramp (air transportable)	3A Onboard folding ramp
Cargo doors	Nose	Nose	Nose	Nose	Nose
Cargo floor	QC panels over commercial freighter floor	QC panels over commercial freighter floor	QC panels over commercial freighter floor	QC panels over commercial freighter floor	QC panels over commercial freighter floor
Loading ramp	Mobile	Mobile	Mobile	Mobile	Onboard, folding
Landing gear	Fixed length	Fixed length	Kneeling	Fixed length	Kneeling
Cargo loading system	Commercial with military capability	Commercial with military capability	Commercial with military capability	Commercial with military capability	Commercial with military capability
Remarks	• Strength capability for main battle tanks • Add-on strengthening for commercial floor substructure included in military conversion kit	• Stabilizing struts incorporated in configuration • Airplane lowered by struts (jacks) after retracting landing gear			

Model 1044-050-	-218	-220	-222	-102	-301	-226
Military freighter features / Primary design option incorporated	4 Aft side cargo door	4A Swing-tail cargo door	5 Lowered military floor	5A Cargo pod	6 Passenger modules	6A Convertible airplane
Cargo doors	Nose + aft side	Nose + swing tail	Nose	Aft ventral	Nose	Nose
Cargo floor	QC panels over commercial freighter floor	QC panels over commercial freighter floor	Military, quick installation	Military, permanent	Military, permanent	QC panels over commercial freighter floor
Loading ramp	Onboard + mobile	Onboard + mobile	Onboard, folding	Onboard, aft ventral	Onboard, folding	Onboard, folding
Landing gear	Kneeling	Kneeling	Kneeling	New, fixed-length gear	Kneeling	Kneeling
Cargo loading system	Commercial with military capability	Commercial with military capability	Military	Military	Military	Commercial with military capability
Remarks	• Onboard ramp serves nose Cargo door • Mobile ramp serves aft cargo door	• Onboard ramp serves nose cargo door • Mobile ramp serves swing-tail cargo door	• Commercial freighter floor and substructure removed • Optimized QC military floor and substructure installed	• Large, outsize capable military cargo pod attached to belly of CRAF passenger airplane • Airplane interior and landing gear removed	• Commercial passenger carried in bus body type modules inside a CRAF commercial version of the military derivative airplane • Passenger escape doors required in airplane fuselage	• Commercial freighter with passenger windows and doors • QC commercial passenger, freighter, military freighter interiors and systems

Figure 4.3.1 CRAF Military Airplane Configurations - Principal Military Freighter Features

Significant features incorporated in study configurations	Dedicated versions: Dedicated commercial passenger transport	Dedicated commercial freighter	Dedicated military freighter	1 Quick-change floor panels – full capability		2 Stabilizing struts		2A Kneeling landing gear
CRAF airplane mode				COML	MIL	COML	MIL	COML
Model 1044-050	-100	-200	-300	-203	-204	-209	-210	-207
1.0 General items								
1.1 Flight crew	3	3	4	3	4	3	4	3
1.2 Crew furnishings, commercial	x	x		x		x		x
1.3 Crew furnishings, military			x	P	x	P	x	P
1.4 Communication and navigation systems, commercial	x	x		x		x		x
1.5 Communication and navigation systems, military			x	P	x	P	x	P
1.6 Pressurized payload compartment	x	x	x	x	x	x	x	x
1.7 Auxiliary power unit	x	x	x	x	x	x	x	x
1.8 Nacelle treatment, engine noise	x	x		x	x	x	x	x
1.9 Inflight refueling system			x	P	x	P	x	P
2.0 Cargo doors and related items								
2.1 Nose cargo door, horizontal swing		x	x	x	x	x	x	x
2.2 Lower lobe cargo doors	x	x		x	x	x	x	x
2.3 Aft side cargo door								
2.4 Swing tail cargo door								
2.5 Support struts, aft body								
3.0 Cargo floors								
3.1 Main deck – vertical location in fuselage	High	High	Low	High	High	High	High	High
3.2 Commercial freighter floor and substructure, permanent		x		x	x	x	x	x
3.3 Commercial freighter floor and substructure, removable								
3.4 Military QC floor panels, drive-on, limited capability								
3.5 Military QC floor panels, drive-on, full capability[a]				P	x	P	x	P
3.6 Military floor and substructure, permanent			x					
3.7 Military floor and substructure, removable								
4.0 Cargo loading and restraint systems								
4.1 Main deck, commercial and military pallet capability		x		x	x	x	x	x
4.2 Main deck, military type integrated with hard floor								
4.3 Powered loading, main deck		x	x	x	x	x	x	x
4.4 Winch loading, main deck			x					
4.5 Lower lobe, commercial and military capability	x	x		x		x		x
5.0 Reduced loading height								
5.1 Landing gear, kneeling			x					P
5.2 Stabilizing struts (onboard jacking system)						P	x	
6.0 Ramps, loading								
6.1 Onboard folding ramp, nose door			x					
6.2 Mobile ramp, Paccar type					x[b]		x[b]	
6.3 Onboard ramp, aft cargo door								
7.0 Increased payload height capability								
7.1 Two floor levels; military floor at lower level								
7.2 Cargo pod on CRAF passenger airplane								
8.0 Commercial passenger and military freighter convertibility								
8.1 Passenger modules in freighter airplane								
8.2 Convertible airplane								
9.0 Commercial passenger related items								
9.1 Passenger windows and doors	x							
9.2 Passenger floor	x							
9.3 Ceilings, wall panels, PSU's, carpets, seats	x							
9.4 Galleys, lavatories, escape systems	x							
9.5 Passenger lighting, air, address, entertainment system	x							
9.6 Passenger oxygen system	x							
9.7 Increased electrical system, kVA	x							
9.8 Fuselage soundproofing, passenger standards	x							

Airplane type: CRAF primary design option

[a]Strengthening for commercial floor substructure included in military floor panel kit. "Full capability" means capability for class 60 vehicles including main battle tanks.

[b]Five airplanes per mobile ramp; first mobile ramp transported to each airlift destination airbase by airplane equipped with onboard ramp.

[c]Aft cargo door inactivated in CRAF commercial mode.

[d]Items checked apply to carrier airplane except as noted.

[e]Cargo pod item.

[f]Passenger module item.

[g]Escape doors required in sides of carrier airplane fuselage (permanent). Escape slides required also (removable).

[h]Quick installation and removal design.

Legend X - Item included in configuration
P - Provisions only in configuration

CRAF airplane versions: Primary design option as indicated

2A. Kneeling landing gear		3. Mobile ramp–Paccar type		3A. Onboard folding ramp–nose door		4. Aft side cargo door		4A. Swing tail		5. Lowered military floor		5A. Cargo pod[d]		6. Passenger modules[d]		6A. Convertible airplane		
COML	MIL	COML	MIL	COML	MIL	COML	MIL	COML	MIL	COML	MIL	COML	MIL	COML	MIL	COML PASS	COML FRTR	MIL FRTR
207	-208	-215	-216	-211	-212	-217	-218	-219	-220	221	222	-101	-102	-302	-301	-223	-225	-226
3	4	3	4	3	4	3	4	3	4	3	4	3	4	3	4	3	3	4
x		x		x		x		x		x		x		x		x	x	
P	x	P	x	P	x	P	x	P	x	P	x	P	x	P	x	P	P	x
x		x		x		x		x		x		x		x		x	x	
P	x	P	x	P	x	P	x	P	x	P	x	P	x	P	x	P	P	x
x	x	x	x	x	x	x	x	x	x	x	x	x	x[e]	x	x	x	x	x
x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
P	x	P	x	P	x	P	x	P	x	P	x	P	x	P	x	P	P	x
x	x	x	x	x	x	x	x	x	x	x	x			x	x	x	x	x
x	x	x	x	x	x	x	x	x	x	x	x	x	x			x	x	x
						x[c]	x											
								x[c]	x				x[e]					
								P	x									
High	High	High	High	High	High	High	High	High	High	High	Low	High	Low[e]	Low	Low	High	High	High
x	x	x	x	x	x	x	x	x	x	x						x	x	x
P	x	P	x	P	x	P	x	P	x							P	P	x
													x[e]	x	x			
											x							
x	x	x	x	x	x	x	x	x	x	x						P	x	x
											x		x[e]	x	x			
x	x	x	x	x	x	x	x	x	x	x				x	x	P	x	x
											x		x[e]					
x		x		x		x		x		x		x				x	x	
P	x			P	x	P	x	P	x	P	x			P	x	P	P	x
				P	x	P	x	P	x	P	x			P	x	P	P	x
	x[b]		x[b]				x[b]		x[b]									
													x[e]					
										x	x							
												P	x					
														x	P			
																x	x	x
												x		x[f]		x	x	x
												x		x[f]				
														x[f]		x[h]	P	P
														x[g]	P[g]	x[h]	P	P
														x[f]	P	x	P	P
														x[f]		x	P	P
												x		x	x	x	x	x
												x		x	x	x	x	x

Figure 4.3.2 Design Options Study Configurations

5.0 DESIGN OPTIONS ANALYSIS

5.1 Introduction

Weight analyses of Design Option configurations are essential for accurate evaluation of benefits and penalties associated with each design. Weight changes directly affect performance and cost estimates. Each configuration must be analyzed in as much detail as possible to permit comparison between alternate designs.

Design Option weight analyses were performed in three steps. First, detail weight statements, following a MIL-STD-1374A Part 1 breakdown, were generated for each of three baseline airplanes: Model 1044-050-100, a dedicated passenger transport; Model 1044-050-200, a dedicated commercial freighter; and Model 1044-050-300, a dedicated military freighter. Next, each design option described in Section 4.3.2 and defined on Figure 4.27 was analyzed in detail to identify weight increments between the option and its baseline configuration, for both commercial and military versions of each configuration. Summary weight statements for all options and baseline aircraft are included in Section 5.4.4. Finally, payload/range and weight comparisons were made of option airplanes with their baselines.

Boeing Level I (statistical/parametric) weight prediction methods were used to establish baseline configuration weights for these studies. Generalized methods are published in Reference 5.1, and specialized methods for airlift airplanes are programmed in a module called "Go Cargo", which is operational in the ASD/XRH airplane design optimization system at WPAFB.

The following sections discuss each of the Design Option Analyses in more detail. Section 5.2 covers weight development for the three baseline configurations. In Section 5.3, each Design Option study is summarized. Ground rules, design criteria, weight increments and weight prediction methods are described. Section 5.4 presents conclusions drawn from data generated for these studies.

5.2 Baseline Airplane Weights Analysis

The baseline configuration for Design Option studies was a dedicated commercial freighter airplane, Model 1044-050-200, described in Section 3.0. This configuration is a low wing airplane with graphite/epoxy primary structure, active flight controls, and advanced engines and aircraft systems. Graphite/epoxy composites, used in both primary and secondary structure, account for approximately 45 percent of the structure weight. Engines were scaled from manufacturer's data for NASA Energy Efficient designs. Fan-air thrust reversers, exhaust mixers and a long-duct nacelle with sound treatment per FAA specified noise levels were also incorporated. Aircraft systems were assumed to be conventional with the exception of weight savings in flight control and hydraulic groups due to advanced technology designs such as fly-by-wire and high pressure hydraulic power systems.

Two additional versions of the baseline airplane were needed to establish reference points for this study. One was a dedicated military freighter with a design payload of 240,000 pounds to accommodate two main battle tanks. A weight summary of this airplane and a table of major differences from the commercial freighter are presented in Figure 5.2.1. A dedicated passenger airplane with the same takeoff gross weight and load factor as the commercial freighter was also configured. It has a capacity of 425 passengers in a typical mixed class interior arrangement.

5.2.1 Dedicated Commercial Freighter

The Dedicated Commercial Freighter baseline which was sized to carry a payload of 200,000 pounds, had a 3,140 miles range capability using ATA International rules. Design gross weight was 522,000 pounds. Weight savings resulting from application of advanced technologies are shown on Figure 5.2.2. If advanced technology features are removed from the commercial freighter and the

Item	Commercial freighter model 1044-050-200		Military freighter model 1044-050-300		Design changes—commercial to military
Structure		128,415 lb		137,342 lb	• Add nose ramp, reinforced military floor, kneeling landing gear, and IFR provisions
Propulsion		30,357 lb		30,557 lb	• Add IFR elements
Fixed equipment and useful load		39,855 lb		37,656 lb	• 4 military versus 3 commercial crew members, military avionics and cargo winch, 463L cargo handling system in lieu of commercial type
Operating weight total	(198,627) lb		(205,555) lb		
Payload		200,000 lb		240,000 lb	• Military payload equivalent of two M-60 tanks in lieu of palletized cargo
Fuel		123,373 lb		142,445 lb	• Mission fuel required for 3,600-nmi range
Mission takeoff weight total	(522,000) lb		(588,000) lb		
Maximum zero fuel weight total	(398,627) lb		(445,555) lb		
Limit maneuver load factor	2.5		2.25		

Figure 5.2.1 Weight Summaries of Baseline Designs

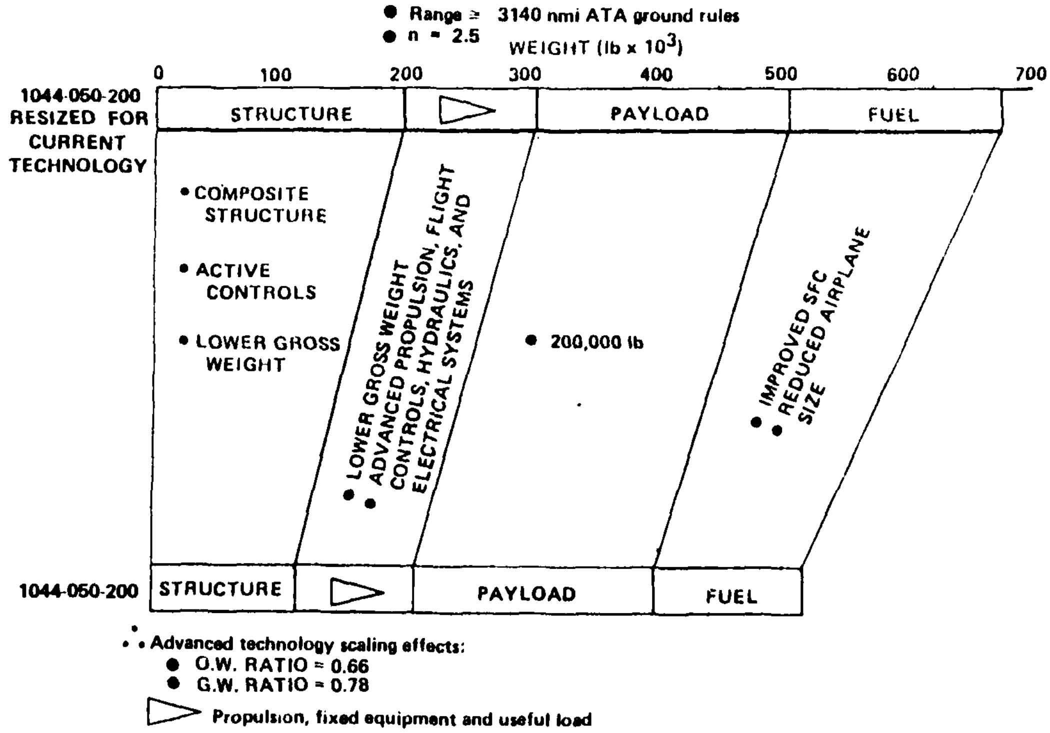


Figure 5.2.2 Commercial Freighter Weight Savings - Resulting from Application of Advanced Technologies

configuration resized to match the mission design point (holding thrust to weight ratio, wing loading and fuselage size constant), the gross weight increases to 670,000 pounds. Thus, the application of advanced technologies reduce operating weight by 34% and gross weight by 22% when compared to a current technology version of the baseline aircraft.

5.2.2 Dedicated Military Freighter

The Dedicated Military Freighter, Model 1044-050-300 was identical externally to the commercial freighter but differed in structural details and payload capacity. The payload was increased to 240,000 pounds to accommodate two main battle tanks. The basic structure for the military airplane was fixed at that of the commercial baseline by reducing the limit maneuver load factor from 2.5 to 2.25. The takeoff gross weight of 588,000 pounds provided sufficient fuel to accomplish the mission.

The differences between the commercial and military baselines are: 1)replacement of commercial floor with military floor and supports, capable of supporting the main battle tank 2) floor is located at a lower waterline to increase the size of the military loading envelope, 3) addition of on board, folding, nose cargo loading ramp, 4) addition of kneeling capability to landing gear, 5) replacement of commercial cargo handling system with military system of flip-over roller trays plus winch, 6) addition of military avionics, crew, furnishings and equipment, 7) addition of in-flight refueling receptacle and plumbing, and 8) removal of nacelle sound treatment.

5.2.3 Dedicated Passenger Transport

The Dedicated Passenger Transport, Model 1044-050-100 had the same takeoff design gross weight and maximum zero fuel weight as the dedicated commercial

freighter, and a limit maneuver load factor of 2.5. It was identical to the commercial freighter except for the following design differences :1) replaced freighter floor and supports with passenger floor, 2) deleted freighter cargo handling system, 3) deleted nose cargo door and mechanism, 4) added passenger windows and door; 5) replaced freighter furnishings with passenger interior and furnishings, 6) revised air conditioning and electrical systems for passenger design loads, and 7) added passenger operating items.

5.3 Design Options Weights Analysis

The Configurations shown on Figure 4.1.1 were selected for evaluation of each design option, as described in Section 4.0. Each was combined with other selected options to form a configuration capable of meeting mission requirements as shown on the configurations summary chart, Figure 4.3.2. In each case the baseline production design was changed to efficiently accept the selected option.

This section summarizes the weight change from the baseline airplanes of Section 5.2 for each study configuration. Scar weight carried by the commercial version and scar weight plus kit weight carried by the military version are listed for each configuration. The total weight increments shown in Figures 5.3.1 through 5.3.11 summarize only the design option changes and do not include other operating weight differences between commercial and military airplanes. Group weight statements for all option configurations are shown on Figure 5.4.7.

5.3.1 Quick Change Floor Panel

Quick Change Floor Option weights are summarized in Figure 5.3.1. The weight analysis was based on past studies that explored a number of floor panel designs and concepts for strengthening the 747 floor support structure. Unit weight of the floor was adjusted to reflect the use of advanced materials and applied to the Design Options Study CRAF freighter floor area to estimate the weight of the quick change panels. Similarily, the increase in floor support weight of the study configuration over that of the 747-200F was used with corrections for advanced technology to estimate study airplane floor

substructure weights. Penalties were added for fittings needed for removable members. The total increase to floor and support weight was apportioned between removable kit and fixed scar increments. Additional scar weight was included for cargo tie-down points and restraining the quick-change floor panels. Weights listed for tie-down devices were based on C-5A actual data for similar equipment.

5.3.2 Stabilizing Struts (Onboard Jacking System)

The Stabilizing Struts Design Options consists of four onboard jacks which raised the airplane high enough off the ground to allow the landing gear to retract, then lowered the airplane to achieve the reduced loading height. The strut design was similar in concept to aircraft ground equipment jacks but had the ability to be retracted and stowed in compartments beneath the main deck.

The struts were constructed of 4340M steel, 275,000 psi heat treat ultimate strength. Weight estimates for the struts were based on preliminary stress sizing of the principal members, i.e., cylinder, piston, legs and braces, with weight added to cover connections, pads, hydraulic fluid, and miscellaneous items. These total 12,400 lb/airplane. Mechanism, controls and support rails were estimated to weigh 20% of the strut weight. The struts, deployment mechanism and rails were considered removable. The only permanent changes to the airplane to accommodate the stabilizing struts are jackpoint fittings, load carry through structure, attachments for support rails, pressurized doors and mechanism, and fixed controls. Weight estimates for these changes totaled 2200 pounds.

Stabilizing strut option weights, alone and in combination with the quick change floor panel option, are summarized on Figure 5.3.2.

Modification	Scar increment, (lb) (model 1044-050-203)	Scar + kit increment, (lb) (model 1044-050-204)
Quick-change panel provisions	+530	+530
Floor supports for military payload	+6,400	+6,400
Quick-change floor panels		+10,600
Underfloor supports		+6,700
Tiedown devices for cargo		+1,750
Total (lb/airplane)	+6,930	+25,980

Figure 5.3.1 Weight Analysis for Quick-change Floor Panel Option

Modification	Scar increment (lb) (model 1044-050-209)	Scar + kit increment (lb) (model 1044-050-210)
Quick-change panel provisions	+530	+530
Floor supports for military payload	+6,400	+6,400
Stabilizing struts provisions	+2,200	+2,200
Stabilizing struts		+12,400
Quick-change floor panels		+10,600
Underfloor supports		+6,700
Tiedown devices for cargo		+1,750
Total (lb/airplane)	+9,130	+40,580

Figure 5.3.2 Weight Analysis for Stabilizing Struts Option

5.3.3 Kneeling Landing Gear

The Kneeling Landing Gear Option is presented for comparison with the stabilizing strut option. Kneeling provisions added to the main and nose landing gears, permitted the cargo floor loading height to be reduced from 168 inches to 125 inches, as described in Section 4.2.3.

A weight summary of all changes required for this design option plus other options included in the reference configuration is presented in Figure 5.3.3. Weight increments for kneeling landing gear are based on C-5A weight data. Changes necessary to allow the gear to kneel increased the main and nose gear assembly weights by an estimated 13 percent.

5.3.4 Mobile Ramp, Air Transportable

This design option illustrates the use of an air-transportable mobile ramp for loading and unloading military vehicles and is described in Section 4.2.4. The weight increments summarized in Figure 5.3.4 were the same as those for the Quick-change floor panel since there was no effect on aircraft scar weight to accommodate the ramp. The estimated weight of the ramp based on vendor quoted data is 30,000 pounds.

5.3.5 Onboard Front Ramp, Folding Type

The Onboard Folding Front Ramp is installed behind the nose cargo door for loading and unloading military vehicles, and was similar to the C-5A installation. It was designed for use with a floor loading height of 125 inches, a deployed ramp angle of 15 degrees, and had the capability to support a main battle tank. Materials assumed in the structure were graphite-epoxy primary structure with titanium fittings and an appropriate hard wearing surface. Design and operational details are discussed in Section 4.2.5.

Weight estimates for this option were based on data in the IADS-77 study, Reference 1.2. The removable ramp weight was estimated to be 474 pounds x loading height x material correction factor. Scar weight was estimated to be 20 percent of ramp weight for sill support and ramp installation. Figure 5.3.5 summarizes the weight changes incorporated in this configuration.

Modification	Scar increment (lb) (model 1044-050-207)	Scar + kit increment (lb) (model 1044-050-208)
Quick change panel provisions	+530	+530
Floor supports for military payload	+6,400	+6,400
Provisions for kneeling gear	+290	+290
Quick-change floor panels		+10,600
Underfloor supports		+6,700
Main gear kneeling		+2,540
Nose gear kneeling		+360
Tiedown devices		+1,750
Total (lb/airplane)	+7,220	+29,170

Figure 5.3.3 Weight Analysis for Kneeling Landing Gear Option

Modification	Scar increment (lb) (model 1044-050-215)	Scar + kit increment (lb) (model 1044-050-216)
Total (lb/airplane)	+6,930	+25,980

These configurations are identical to the quick-change floor models 1044-050-203 and -204.

Figure 5.3.4 Weight Analysis for Mobile Ramp Option

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DESIGN OPTIONS STUDY.(U)
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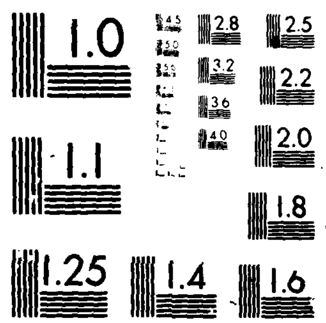


MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

5.3.6 Rear Side Cargo Door

The Rear Side Cargo Door provided a main deck cargo loading opening 137 inches high by 200 inches long, and was located in the fuselage on the left side, aft of the wing. The design was similar to a 747-200F installation, and is described in Section 4.2.6.

The materials were assumed to be graphite-epoxy primary structure with titanium fittings. The weight increment were based on 747-200F weight data, adjusted for use of advanced materials. The entire weight change except for an aft body support strut was assumed to be scar weight. Figure 5.3.6 summarizes changes incorporated in this configuration.

5.3.7 Swing Tail Cargo Door

This design option provided an aft cargo loading opening by means of a hinged joint placed in the body at Station 2220, allowing the aft body and empennage to swing upward. A full-width opening provided which allowed drive through capability. This option is described in Section 4.2.7.

Materials used were assumed to be graphite-epoxy doublers and titanium fittings. Weight increments are based on a 747 study of a similar installation, with adjustments for use of advanced materials, plus an estimate for fuselage support struts added below the loading sill. The total weight increment, except for the support struts, is assumed to be scar weight. Figure 5.3.7 summarizes the weight changes included in this configuration.

5.3.8 Lowered Military Floor

The Lowered Military Floor concept utilized two separate floor and floor support installations, a commercial freighter floor at a height that allows clearance for LD-3 containers below the floor for commercial operation, and a higher-strength military floor installed at a lower level that increased the main deck payload envelope for the military version. To convert from commercial to military operation, the commercial floor, floor beams and supports and cargo handling system were completely removed, and replaced by

Modification	Scar increment (lb) (model 1044-050-211)	Scar + kit increment (lb) (model 1044-050-212)
Quick-change panel provisions	+530	+530
Floor supports for military payload	+6,400	+6,400
Provisions for kneeling gear	+290	+290
Provisions for folding nose ramp	+790	+790
Quick-change floor panels		+10,600
Underfloor supports		+6,700
Kneeling gear		+2,900
Tiedown devices		+1,750
Folding nose ramp		+3,940
Total (lb/airplane)	+8,010	+33,900

Figure 5.3.5 Weight Anaylsis for Multileaf Folding Ramp (Onboard) Option

Modification	Scar increment (lb) (model 1044-050-217)	Scar + kit increment (lb) (model 1044-050-218)
Quick-change panel provisions	+530	+530
Floor supports for military payload	+6,400	+6,400
Provisions for kneeling gear	+290	+290
Provisions for folding nose ramp	+790	+790
Rear side cargo door installed	+5,390	+5,390
Support for aft body struts	+100	+100
Quick-change floor panels		+10,600
Underfloor supports		+6,700
Kneeling gear		+2,900
Tiedown devices		+1,750
Folding nose ramp		+3,940
Aft body support struts		+300
Total (lb/airplane)	+13,500	+39,690

Figure 5.3.6 Weight Anaylsis for Rear Side Cargo Door Option

the military floor, supports and cargo handling system, as described in Section 4.2.8.

The weights of both commercial and military floor installations were estimated from Level I statistical methods. These weights were increased by 20 percent to account for fittings in the floor and floor beams to make them removable. Scar weight carried by the commercial freighter for this design option consisted of (1) fittings at two levels on the body frames and bulkheads, on floor beams and on the floor itself; (2) reinforcement in the frames and bulkheads for military cargo loads; and (3) fittings for added military underfloor support members. The net conversion kit weight was the difference between the commercial and military floor and floor beam assemblies, plus added supporting members installed with the military floor. Figure 5.3.8 summarizes the weight changes incorporated in this configuration.

5.3.9 Cargo Pod

This design option by attaching a cargo pod beneath a commercial passenger airplane provided an oversize military payload envelope, as compared to the commercial freighter cross-section.

The weight analysis of this option was performed as follows:1) The pod structure, landing gear and systems weights were estimated from statistical aircraft data. Materials were largely graphite/epoxy.2) The baseline passenger aircraft (Model 1044-050-100) was prepared for the conversion by removing weight of landing gear, accommodations for passengers and passenger operating items (food, liferafts, galleys, cargo containers, etc.);3) Scar weight was added to the baseline for additional structure in the basic body required to distribute pod loads and horizontal tail reinforcement to support fins added for directional stability. The cargo pod support and attachment problems were analogous to the 747 space shuttle installation, therefore weight increments for these features were established from actual data. Figure 5.3.9 summarizes weight changes made to derive the cargo pod option configurations.

Modification	Scar increment (lb) (model 1044-050-219)	Scar + kit increment (lb) (model 1044-050-220)
Quick-change panel provisions	+530	+530
Floor supports for military payload	+6,400	+6,400
Provisions for kneeling gear	+290	+290
Provisions for folding nose ramp	+790	+790
Kneeling gear		+2,900
Install swing tail	+5,700	+5,700
Quick-change floor panels		+10,600
Support for aft body strut	+100	+100
Underfloor supports		+6,700
Tiedown devices		+1,750
Folding nose ramp		+3,940
Aft body strut		+300
Total (lb/airplane)	+13,810	+40,000

Figure 5.3.7 Weight Anaylsis for Swing Tail Option

Modification	Scar increment (lb) (Model 1044-050-221)	Scar + kit increment (lb) (Model 1044-050-222)
Lower floor provisions	+8,350	+ 8,350
Provisions for kneeling gear	+ 290	+ 290
Provisions for folding nose ramp	+ 790	+ 790
Replace commercial floor with lower military floor		+ 7,810
Replace commercial cargo handling with military system		– 4,910
Kneeling gear		+ 2,900
Folding nose ramp		+ 3,940
Tiedown devices		+ 1,750
Total (lb/airplane)	+9,430	+20,920

Figure 5.3.8 Weight Anaylsis for Lowered Military Floor Option

5.3.10 Passenger Modules

This design option studied conversion of the Dedicated Military Freighter Model 1044-050-300, into a passenger transport by placing eight fully loaded passenger modules into the airplane. Each module had a passenger capacity of 44. Galleys and toilets were located outside of passenger modules. Section 4.2.10 describes this option in more detail. Figure 5.3.10 summarizes the weight changes.

Scar weight added to the military airplane included installation of passenger entry and escape doors and nacelle treatment for airport noise reduction. Weight changes made during the conversion to a passenger airplane account for: 1) removal of the kneeling landing gear feature and folding nose loading ramp, and 2)addition of powered roller system for module handling and the modules themselves.

Boeing Vertol weight prediction methods, Reference 5.2, were used for estimating the passenger module structure weight. Weights of the passenger module equipment and passenger furnishings and equipment were estimated from empirical data. Structure weight for one module was estimated to be 3680 pounds. Equipment and systems weight for one module was 3240 pounds.

5.3.11 Convertible Airplane

This design option, described in Section 4.2.11, examined a convertible passenger-commercial cargo airplane similar to the 747-200 convertible but with added provisions for enhanced military freighter capability.

Weight changes made to the commercial freighter for each variation are summarized in Figure 5.3.11. Column 1 lists the scar weight increments added to the commercial freighter to allow conversion to either passenger or military configurations. Column 2 lists scar weights plus military freighter conversion items. Column 3 lists similar data for the commercial passenger version.

Modification	Scar increment (lb) (Model 1044-050-101)	Scar + kit increment (lb) (Model 1044-050-102)
Provisions for pod support	+4,500	+4,500
Provisions for added fins	+610	+610
Remove accommodations for passengers		-22,000
Remove operating items (food, liferafts, galleys, cargo containers, etc.)		-34,890
Add tip fins		+2,000
Install cargo pod and support structure		+38,020
Install cargo pod electrical and hydraulic systems		+600
Replace airplane landing gear with pod gear		+5,700
Total (lb/airplane)	+5,110	-5,460

Figure 5.3.9 Weight Anaylsis for Cargo Pod Option

Modification	Scar increment (lb) (model 1044-050-302)	Scar + kit increment (lb) (model 1044-050-301)
Install passenger entry doors	+3,500	+3,500
Remove and add kneeling gear	-3,900	0
Remove and add folding ramp	-3,940	0
Add and remove powered load handling system	+7,930	0
Add and remove operating items (food, water, galleys, etc.)	+29,710	0
Add and remove passenger modules and equipment	+55,360	0
Add engine noise abatement	+1,000	+1,000
Total (lb/airplane)	+89,660	+4,500

Figure 5.3.10 Weight Anaylsis for Passenger Module Option

Modification	Scar increment (lb) (model 1044-050-225 commercial freighter)	Scar + kit increment (lb) (model 1044-050-226 military freighter)	Scar + kit increment (lb) (model 1044-050-227 commercial passenger)
Provisions for kneeling gear	+290	+290	+290
Quick-change panel provisions	+530	+530	+530
Floor supports for military payload	+6,400	+6,400	+6,400
Provisions for folding nose ramp	+790	+790	+790
Add passenger windows and doors	+5,540	+5,540	+5,540
Add electrical equipment for passenger provisions	+2,340	+2,340	+2,340
Add air-conditioning and anti-icing for passenger conversion	+1,540	+1,540	+1,540
Main gear, kneeling		+2,540	
Nose gear, kneeling		+360	
Quick-change floor panels		+10,600	
Underfloor supports–removable		+6,700	
Tiedown devices for cargo		+1,750	
Folding nose ramp		+3,940	
Passenger furnishings			+33,060
Remove commercial cargo handling system			−13,840
Add cabin crew			+1,710
Add operating items (food, liferafts, galleys, cargo containers, etc.)			+34,890
Total (lb/airplane)	+17,430	+43,320	+73,250

Figure 5.3.11 Weight Anaylsis for Convertible Airplane Option

Weight increments used for these comparisons were the same as developed for other phases of this study. Passenger related changes were based on data used for the dedicated passenger airplane, while increments included to cover conversion to a military freighter were the same as tabulated for the quick-change floor panel option.

5.4 Summary and Technology Assessments

This section presents a summary of the weight analyses study results. Military and commercial payload reductions caused by scar and kit weights and their effects on the payload-range capabilities of the baseline aircraft are shown. The weight savings of graphite-epoxy structure usage for each of the design options are compared for military and commercial designs.

5.4.1 Comparison of Configuration Weight Penalties

Figure 5.4.1 shows the commercial scar weight and the military payload reduction resulting from each design option studied.

Commercial scar weights included provisions for inflight refuelling (IFR) and military avionics in addition to design option change provisions. Military payload weight reductions included IFR equipment, military avionics, extra furnishings and one more crew member in addition to scar plus kit weights.

The following conclusions can be drawn from Figure 5.4.1:

1. The kneeling gear option is more weight efficient than use of stabilizing struts.
2. The mobile ramp is lighter than the onboard ramp.
3. Rear side cargo door and swing tail have nearly equal weight penalties.
4. A lowered military floor is significantly lighter than the cargo pod, for the military freighter comparison.
5. For the commercial case convertibles weigh less than the passenger modules.

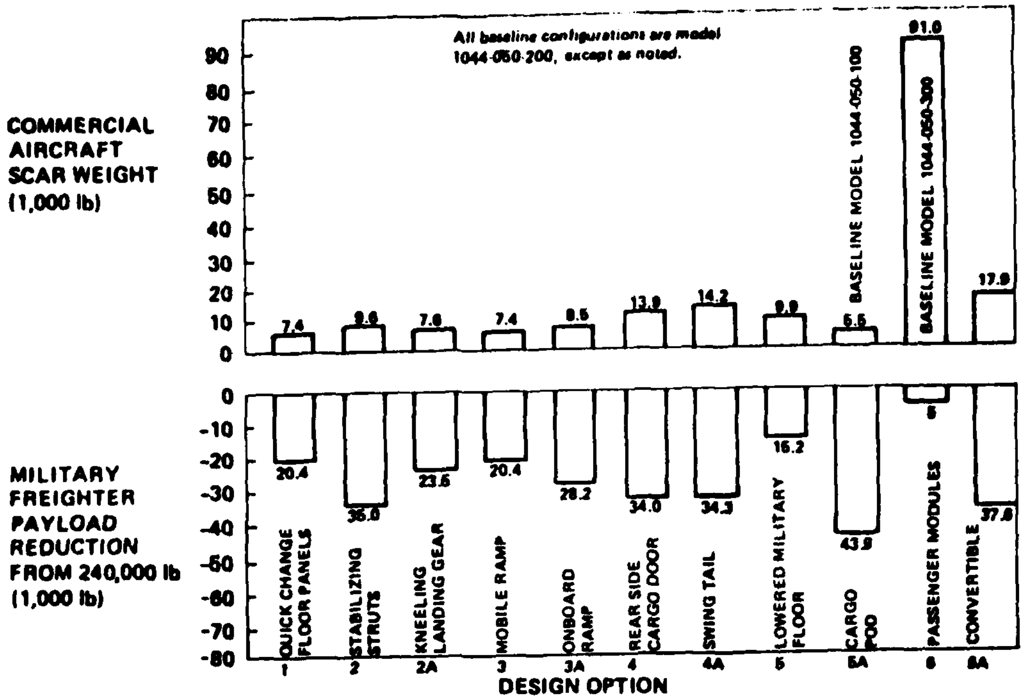


Figure 5.4.1 CRAF Commercial and Military Transport Weight Penalties

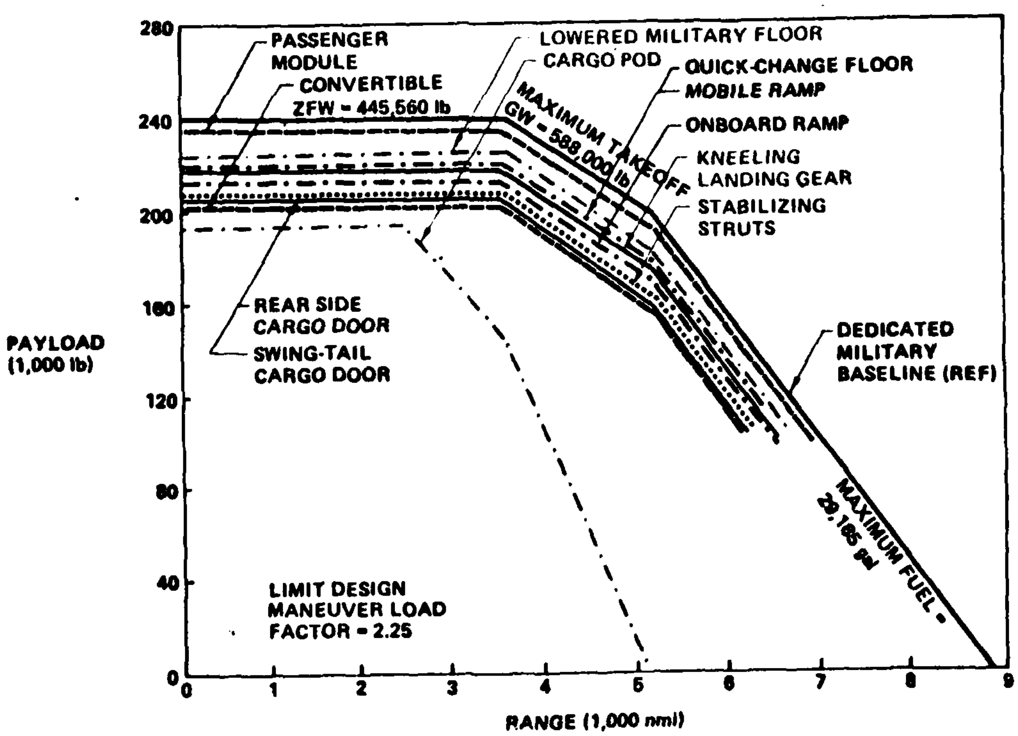


Figure 5.4.2 CRAF Military Freighter Capabilities

5.4.2 Military and Commercial Configuration Payload/Range Capabilities

Figure 5.4.2 shows the payload range trades for the military freighters with scar and kit weights included. Since constant maximum zero fuel weight of 445,560 pounds was used in the study , all maximum payloads were carried 3,600 nmi at the maximum takeoff weight of 588,000 pounds. The first slope shows the effects of trading fuel for payload until the maximum fuel capacity of 29,185 gallons is reached. The second slope shows the effects on range of reducing payload and maintaining maximum fuel. The cargo pod option design never reaches 3600 nmi range with its maximum payload and has the poorest payload-range capabilities because of the large added drag and weight of the pod.

Figure 5.4.3 includes payload-range charts for the Enhanced Commercial Freighter configurations with design options incorporated. The degree of maximum payload reduction due to considering the best and worst option is 10%, and the worse option case also reduces the maximum range by 5%.

Figure 5.4.4 contains payload-range data for the Enhanced Commercial Passenger configurations with design options incorporated. The passenger module is the poorest option because of the redundant weight of the module structures. This configuration is also limited to 352 passengers because of module installation space requirements within the military pressurized fuselage.

As previously noted, the Design Option configurations were analyzed by holding maximum zero fuel weight constant and trading payload for increased operating weight. In order to meet the desired military mission of carrying a 240,000 pound payload for 3,600 nmi range, a military freighter fitted with the various design options would necessarily require an increase in gross weight. A preliminary estimate of the gross weight increase required was calculated, based

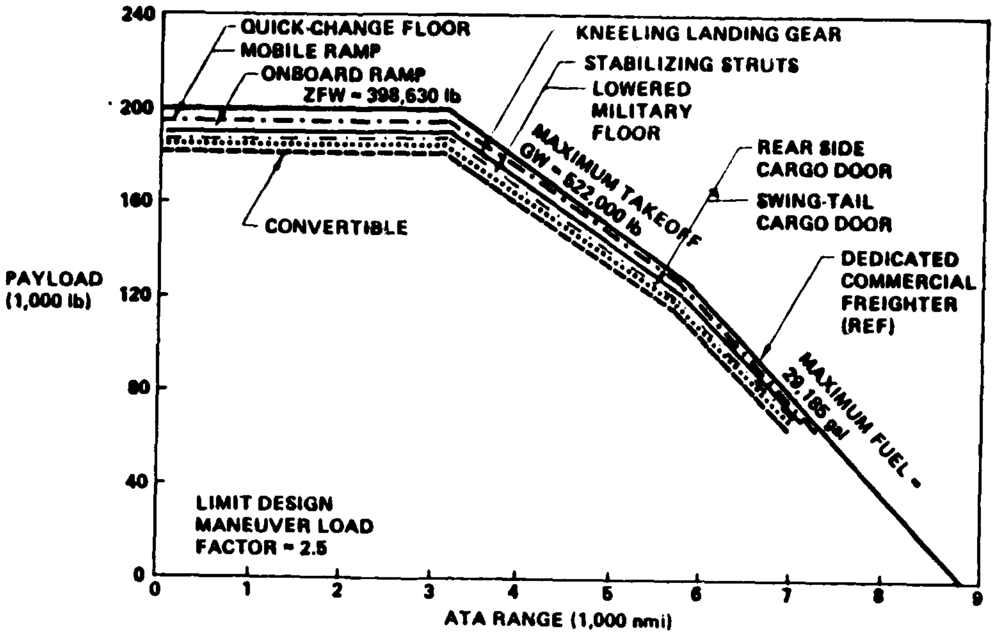


Figure 5.4.3 CRAF Commercial Freighter Capabilities

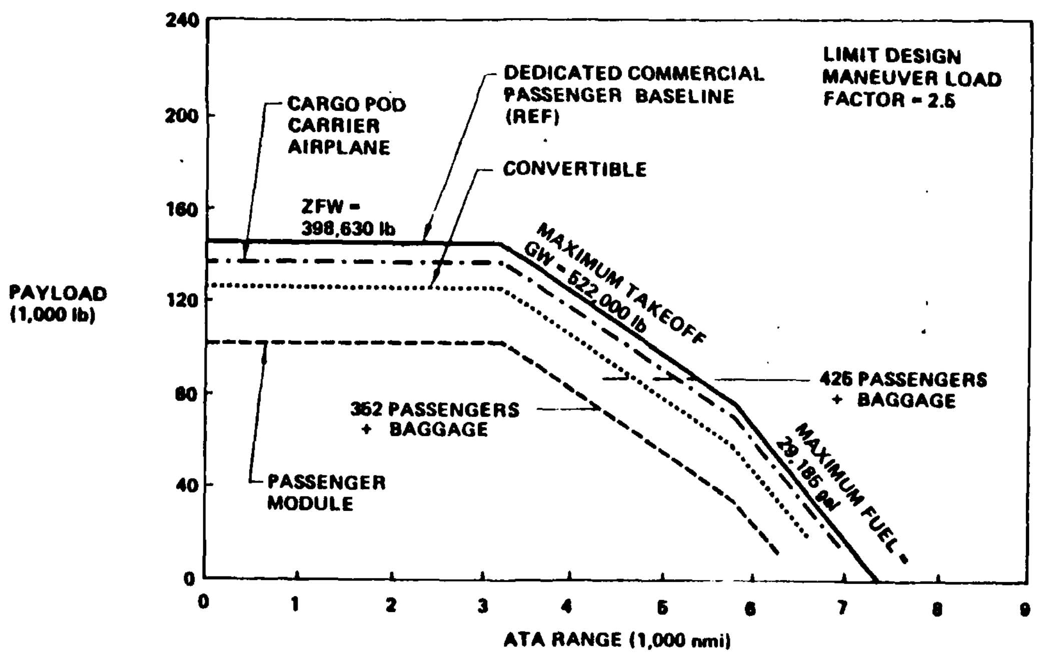


Figure 5.4.4 CRAF Commercial Passenger Capabilities

upon use of the Quick-Change Floor Panel Option as an example. This particular configuration, Model 1044-050-204, had a military payload of 219,600 pounds. Resizing this configuration to carry a payload of 240,000, holding engine thrust to weight ratio, wing loading and fuselage size constant, required a gross weight of 640,000 pounds compared to the initial gross weight of 588,000 lbs.

5.4.3 Effect of Advanced Technology Applications on Design Options

All advanced technology developments that will be available for a mid 1990 IOC date airplane will certainly be incorporated into the design options.

Since the use of graphite/epoxy structure is the most effective new technology for design options, a weight savings chart was developed indicating the amounts of weight savings included for each option of this study (see Figure 5.4.6). These are incremental weights, i.e., uncycled, which means that they do not include airplane growth factors required to retain constant mission performance. Implied in these results is a greater degree of risk for the military option case since the incremental weight savings are greater than for the commercial.

5.4.4 Weight Summaries

Figure 5.4.7 contains the weight build-ups and summaries for the baseline and design option configurations. The design descriptions were shown on Figure 4.3.3. It should be noted on Figure 5.4.7 that maximum zero fuel weights of all commercial aircraft were held constant at 398,627 pounds. Similarly, the military cargo configurations also retained a constant zero fuel weight of 445,555 pounds. The zero fuel weight ground rule was used for the study in order to facilitate ranking of the options in a meaningful way. Increase in operating weight requires a like decrease in payload under these ground rules.

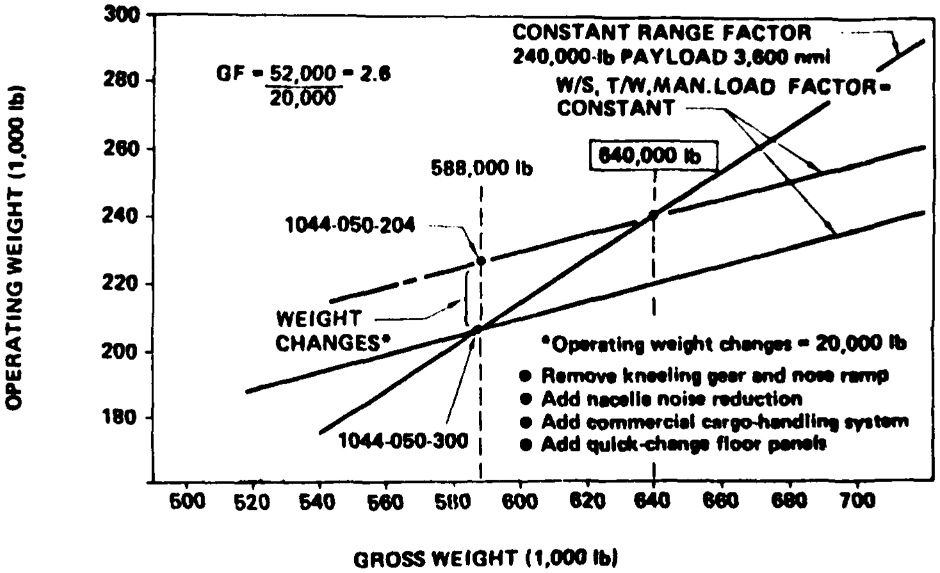


Figure 5.4.5 Resized Military CRAF Freighter - 240,000 lb. Payload and Quick-change Floor Panel Option

- Advanced technology items that are geared to an aircraft IOC date of 1990 were incorporated into the baseline and design options configurations.
- Graphite-epoxy structure is the most weight effective advanced technology considered in the design options study.
- Design option modifications and added structure are assumed to have the same degree of graphite-epoxy use as the baseline airplane.
- Uncycled structure weight savings for each option, due to using graphite-epoxy, are:

	Weight saving (lb/airplane)[a]		
Option	Commercial cargo[b]	Military cargo[c]	Passenger
1. Quick-change floor panels	1,755	6,090	NA
2. Stabilizing struts	2,305	6,640	NA
2A. Kneeling gear	1,755	6,340	NA
3. Mobile ramp	1,755	6,090	NA
3A. Onboard ramp	1,955	7,540	NA
4. Rear side cargo door	3,330	8,915	NA
4A. Swing tail	2,480	8,065	NA
5. Lowered military floor	2,315	5,525	NA
5A. Cargo pod	1,345	14,025	NA
6. Passenger modules	NA	1,485	255[b]
6A. Convertible airplane	1,955	7,540	1,955[b]

[a]Compared to current state-of-the-art structure [b]Scar weight savings [c]Scar + kit weight savings

Figure 5.4.6 Technology Identification for Design Options

Item	Airplane type	Dedicated versions			CRAF airplane versions: Primary design option as indicated							
	CRAF primary design option	Dedicated commercial passenger transport	Dedicated commercial freighter	Dedicated military freighter	1. Quick-change floor [illegible]		2. Stabilizing struts		2A. Kneeling landing gear		3. Mobile ramp—Pallet type	
	CRAF airplane mode				COML	MIL	COML	MIL	COML	MIL	COML	MIL
	Model 1044-[illegible]	-100	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-310	-307	[illegible]	-318	[illegible]
Structure		126711	128415	137342	135445	135485	137645	137685	135654	138593	135445	135485
Propulsion		30357	30357	30557	30557	30557	30557	30557	30557	30557	30557	30557
Fixed Equipment		58365	37465	34081	37611	38995	37611	38995	37611	38995	37611	38995
Weight Empty		215433	196237	201980	203613	205037	205813	207237	203822	208145	203613	205037
Operating Items		38684	2390	3575	2390	20875	2390	33275	2390	20875	2390	20875
Operating Weight		254117	198627	205555	206003	225912	208203	240512	206212	229020	206003	225912
Payload		144510	200000	240000	192624	219643	190424	205043	192415	216535	192624	219643
Zero Fuel Weight		398627	398627	445555	398627	445555	398627	445555	398627	445555	398627	445555
Fuel		123373	123373	142445	123373	142445	123373	142445	123373	142445	123373	142445
Maximum Gross Weight		522000	522000	588000	522000	588000	522000	588000	522000	588000	522000	588000
Design Options Incorporated		None	None	Onboard Ramp[a] Kneeling L.G.[a]	Q.C. Floor Mobile Ramp		Q.C. Floor Mobile Ramp		Q.C. Floor Mobile Ramp		Q.C. Floor Mobile Ramp	

Item	3A. Onboard folding ramp—nose door		4. Aft side cargo door		4A. Swing tail		5. Lowered military floor		5A. Cargo pod		6. Passenger modules		6A. Convertible airplane		
CRAF airplane mode	COML	MIL	COML	MIL	COML	MIL	COML	MIL	COML	MIL	COML	MIL	COML PASS	COML FRTR	MIL FRTR
Model 1044-[illegible]	-311	-312	-317	[illegible]	[illegible]	[illegible]	-321	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Structure	136443	143326	141033	149116	142243	149426	137063	152556	121821	111660	134963	141082	141983	141983	148866
Propulsion	30557	30557	30557	30557	30557	30557	30557	30557	30557	30557	30557	30557	30557	30557	30557
Fixed Equipment	37611	38995	37611	38995	37611	38995	37611	34081	58811	37041	41671	34081	60701	41484	42868
Weight Empty	204611	212878	210101	218668	210411	218970	206031	217194	229989	179250	207191	206400	233241	214024	222291
Operating Items	2390	20875	2390	20875	2390	20875	2390	3571	30684	70195	88510	3575	38684	2390	20875
Operating Weight	207001	233753	212491	239543	212801	239853	208421	220769	259673	249463	295701	210086	271925	216414	243166
Payload	191626	211802	186136	206012	185826	205702	190206	224786	138954	196102	102926	235560	126702	182213	202389
Zero Fuel Weight	398627	445555	398627	445555	398627	445555	398627	445555	398627	445555	398627	445555	398627	398627	445555
Fuel	123373	142445	123373	142445	123373	142445	123373	142445	123373	142445	123373	142445	123373	123373	142445
Maximum Gross Weight	522000	588000	522000	588000	522000	588000	522000	588000	522000	588000	522000	588000	522000	522000	588000
Design Options Incorporated	Q.C. Floor Onboard Ramp Kneeling L.G.		Q.C. Floor Onboard Ramp Kneeling L.G. Mobile Ramp[b]		Q.C. Floor Onboard Ramp Kneeling L.G. Mobile Ramp[b]		Lowered Floor Onboard Ramp Kneeling L.G.		Cargo Pod		Pass. Modules Onboard Ramp Kneeling L.G.		Q.C. Floor Onboard Ramp Kneeling L.G. Q.C. Interior		

[a] Optimized Version For Permanent Installation.

[b] Mobile Ramp Serves Aft Cargo Door;
No Impact on Airplane Operating Weight.

Figure 5.4.7 Weight Summary - Design Options Study Airplanes

6.0 SYSTEM COSTS

6.1 Introduction

The purpose of this section is to provide visibility on how system costs were generated. As shown on Figure 6.1.1, the subjects of this section are Life Cycle Costs, Commercial Pricing, and Commercial Economics, which includes airline Direct Operating Costs and Return on Investment (ROI).

Two pricing approaches, shown on Figure 6.1.2, were utilized to estimate acquisition costs to the government. The first, commercial pricing with a constant ROI to the manufacturer at all quantities, was used for all aircraft and options. This is consistent with the basic assumptions that the airplane program would be a commercial program, would be commercially funded, and that the government would buy airplanes at commercially based prices. The second approach was to price military kits at cost plus 10 percent for profit. The majority of the cost results will be provided in Section 7.0, Design Options Evaluation.

6.2 Military Life Cycle Costs (LCC)

Military Life Cycle Costs are stated in FY 1978 dollars and include the costs to the government for acquisition -- development, production, and support investment-- and ownership of a system. Commercial pricing by its nature includes both development and production costs in a single price. Support investment costs are factored at 15 percent of acquisition costs.

The LCC ground rules are shown on Figure 6.2.1. These are consistent with past studies such as NSAC-New Strategic Airlift Concepts, Reference 6.1, and IADS-Innovative Aircraft Design Study.

Utilizing these ground rules, the Dedicated Military Freighter (DMF) ownership cost to the government for one 18 UE squadron for one year is $58.8M. The detail of this cost is given on Figure 6.2.2. Fuel and maintenance costs drive the total operating and support cost.

- Life cycle costs (LCC)

- Commercial pricing

- Commercial economics–DOC, ROI

Figure 6.1.1 Cost Anaylsis

- Commercial pricing approach–constant ROI to manufacturer
  - Dedicated commercial freighter (DCF)–baseline
  - Dedicated military freighter (DMF)
  - All options
- Military pricing approach–cost plus 10%
  - Military kits

Figure 6.1.2 Pricing Methodology

• Year of dollars	FY 1978
• Operating period	20 yr
• Type of aircraft program	Commercial, with a military derivative
• Airplane buy quantity	120% of UE
• Flying hours	1,000 per UE per year
• Fuel price	$0.42 per gal
• Support investment	15% of acquisition cost
• Operating and support cost model	CACE model from AFR 173-10

Figure 6.2.1 Ground Rules - Life Cycle Cost

Cost element	Annual squadron cost ($)–18 UE
Aviation fuel	10.800
Base maintenance	15.944
Depot maintenance	16.853
Replenishment spares	5.598
Other	9.608
Total	$58.803
Cost/UE/yr	$ 3.267

Figure 6.2.2 Operating and Support Costs - Dedicated Military Freighter (FY 1978 Dollars in Millions)

6.3 Commercial Pricing and Economics

An overview of the procedure for developing commercially based prices is provided in Figure 6.3.1. As a first step, the commercial price for the baseline Dedicated Commercial Freighter (DCF) was estimated. To this was added the separately estimated price delta for the Dedicated Military Freighter(DMF) derivative at the quantities of interest. This provides the military price level for the DMF. The option airplane prices were also based on the DCF price with delta prices added for options and commercial kits. The convertible airplane price is the sum of the commercial passenger airplane price and delta prices for options and kits. The passenger module airplane price is the sum of the dedicated freighter airplane price and delta prices for options and kits.

The development and production costs which went into the commercial price calculations were developed in considerable detail. Utilizing group weight statements which provides the weight breakdown of a system as the point of departure, costs were generated to fill the matrices shown on Figures 6.3.2 and 6.3.3, respectively. The cost estimates were based on Boeing history, industry data, and vendor quotes, and involved estimating each functional line item of cost for each major system element together with the appropriate rates and factors. The costs for the systems in this study are not shown due to the proprietary nature of such costs.

Once the cost base for a system has been established, the procedure known as Return on Investment pricing begins. Figure 6.3.4, notes the airplane price drivers and the reasons for ROI pricing. The magnitude and timing of the program costs and sales together with the ROI required by the manufacturer are the most significant price drivers. ROI pricing is employed by the manufacturer to account for risk due to the delay of recovering the initial investment and the attendant interest payments, risk related to whether predicted sales materialize, and risk involved with the ability to achieve technical and cost objectives. ROI pricing also accounts for a reasonable profit.

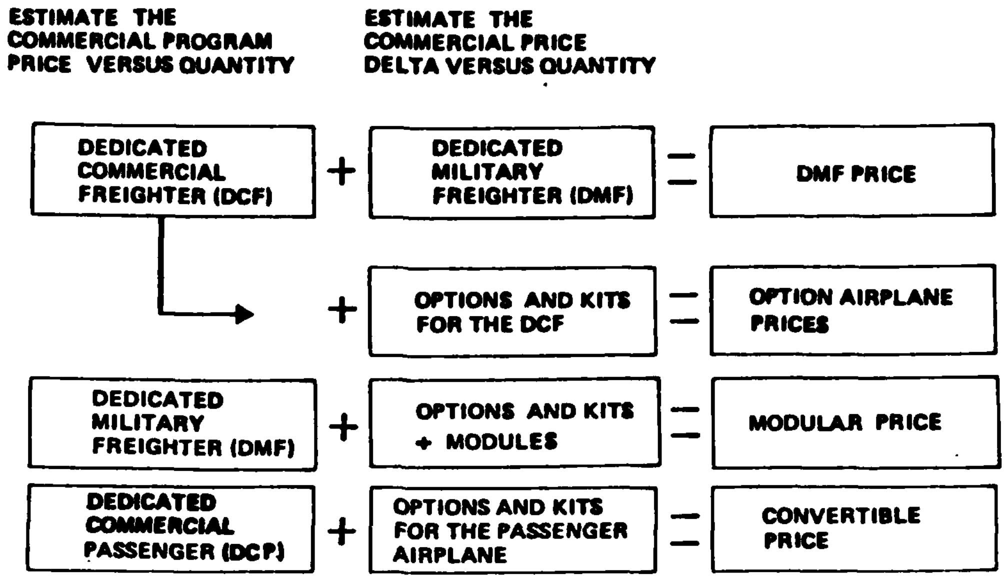


Figure 6.3.1 Commercial Pricing Roadmap

NON-RECURRING
DESIGN OPTIONS STUDY
1044-150-200

DOLLARS 000'S	WING	FUSELAGE	EMP.	LDG.	PROP.	SYSTEMS	FIN. ASSY	ENGINES	OTHER	TOTAL
ENGINEERING LABOR										
DEVELOPMENTAL LABOR										
TOOLING LABOR										
PRODUCTION LABOR										
QUALITY CONTROL										
LABOR DOLLARS										
DEVELOPMENTAL MATL.										
TOOL MATERIAL										
PRODUCTION MATL.										
PURCHASED EQUIPMENT										
OUTSIDE PRODUCTION										
ENGINES										
FLIGHT TEST										
COMPUTING										
WDT										
ENGINEERING OVHD.										
MANUFACTURING OVHD.										
FACILITIES CAPITAL										
FRINGE BENEFITS										
SUBTOTAL COSTS										
DIRECT CHARGES										
SUBCONTRACTOR PROFIT										
TOTAL COST										
TOTAL COST + ADJ.										
HOURS 000'S										
ENGINEERING										
DEVELOPMENTAL										
TOOLING										
PRODUCTION										
QUALITY CONTROL										
TOTAL OPERATIONS										

Figure 6.3.2 Development Cost Detail

DESIGN OPTIONS STUDY—[illegible] A/P [illegible]
1044-150-200

DOLLARS 000'S	WING	FUSELAGE	EMP.	LDG.	PROP.	SYSTEMS	FIN. ASSY	ENGINE	OTHER	TOTAL
ENGINEERING LABOR										
DEVELOPMENTAL LABOR										
TOOLING LABOR										
PRODUCTION LABOR										
QUALITY CONTROL										
LABOR DOLLARS										
DEVELOPMENTAL MATERIAL										
TOOL MATERIAL										
PRODUCTION MATERIAL										
PURCHASED EQUIPMENT										
OUTSIDE PRODUCTION										
ENGINES										
FLIGHT TEST										
COMPUTING										
WDT										
ENGR. OVERHEAD										
MFG. OVERHEAD										
FACIL. CAPITAL										
FRINGE BENEFITS										
SUBTOTAL COST										
DIRECT CHARGES										
SUBCONT. PROFIT										
TOTAL COST										
TOTAL COST + ADJ										
HOURS 000'S										
ENGINEERING										
DEVELOPMENTAL										
TOOLING										
PRODUCTION										
QUALITY CONTROL										
TOTAL OPERATIONS										

Figure 6.3.3 Production Cost Detail

- **Airplane price drivers:**
  - **Magnitude of the development and production costs**
  - **Timing of the development and production costs**
  - **Timing of the deliveries (sales dollars)**
  - **ROI required by the manufacturer**
- **Reasons for ROI pricing:**
  - **Accounts for manufacturer's risk**
    - **Delay of initial investment recovery**
    - **Materialization of sales**
    - **Ability to achieve technological and cost objectives**
  - **Provides for a reasonable profit**

Figure 6.3.4 Commercial Program - Constant ROI Pricing (Part I)

Figures 6.3.5 and 6.3.6 provide conceptual and simplified examples of ROI pricing. In Step 1, Figure 6.3.5, the manufacturer's program costs are time-phased for each quantity in the manner shown.

In Step 2 these costs are discounted back to time "0" at the required ROI percent. The bars of $1,000M for development and $4,600M for production represent the Step 1 costs as if the costs had occurred at particular points in time--an over-simplification for purposes of explanation. These are the costs that will be discounted.

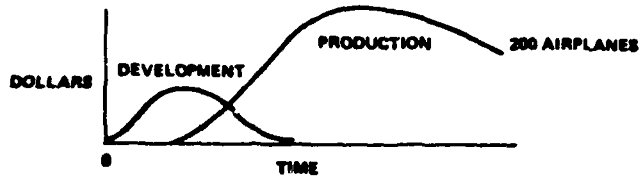
Discounting is the reverse of compound interest. $0.83 invested now at 10 percent interest will be worth $0.91 a year from now and $1.00 in two years. Discounting this $1.00 back two years to present at 10 percent makes its present worth $0.83 assuming 10 percent can be earned on money invested today. Since the object of discounting is to find the present worth of different streams of cash flows so they may be compared, the program costs in this example will be equated with sales dollars in terms of present worth. The ROI discount percent is assumed to include the interest to be paid on borrowed capital, a margin to cover risk as mentioned earlier, and a reasonable profit percentage.

Since it has been shown that future dollars are worth less now, the example assumes that the required ROI percent makes the present worth of the $1,000M equal to .50 of $1,000M and the present worth of the $4,600M equal to .10 of $4,600M. Dollars farther out in the future are worth even less now. The present worth of the discounted costs becomes $960M.

In Step 3 on Figure 6.3.6 the timing of system deliveries is projected for each quantity. In Step 4 the deliveries in terms of sales dollars (200 deliveries times the yet-to-be-determined sales price) are represented by a bar the same as for costs in Step 2. These sales dollars also have a present worth. In this example it is assumed to be .08 times 200 deliveries times the sales price. Equating the present worth of the costs and the sales and solving for the price results in a $60M price for each system at quantity 200.

- **Simplified example**

Step 1. Time phase program costs (each quantity)



Step 2. Discount costs back to time "0" at required ROI percent

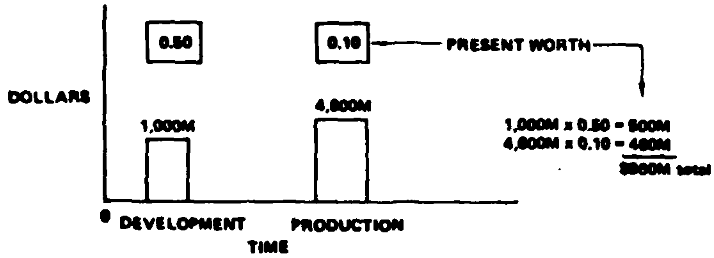
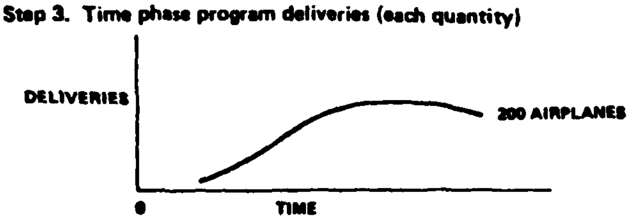


Figure 6.3.5 Commercial Program - Constant ROI Pricing (Part II)

- **Simplified example (continued)**

Step 3. Time phase program deliveries (each quantity)



Step 4. Discount deliveries back to time 0 at required ROI percent

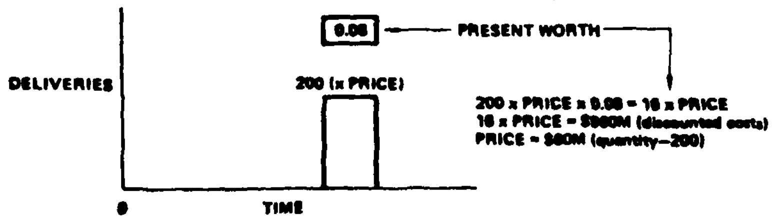


Figure 6.3.6 Commercial Program - Constant ROI Pricing (Part III)

The baseline Dedicated Commercial Freighter price was calculated in the manner just described and was taken from the price curve at quantity 600 as shown in Figure 6.3.7. Forecasts project that the commercial market for a DCF around the turn of the century would equal or exceed 600 aircraft. The actual price used is not shown since it is proprietary information.

An example of the price versus quantity leverage for the quick-change floor option is also shown on Figure 6.3.7. Analysis indicates the requirement for this option is about 150 units. The average cost for 150 units is 279 percent of the average cost of 600 units--170 percent higher. Total cost for 150 units is about two-thirds of the total cost for 600.

The ground rules for direct operating cost and return on investment calculations in this study are shown on Figure 6.3.8. Design Options cost results are presented in Section 7.0.

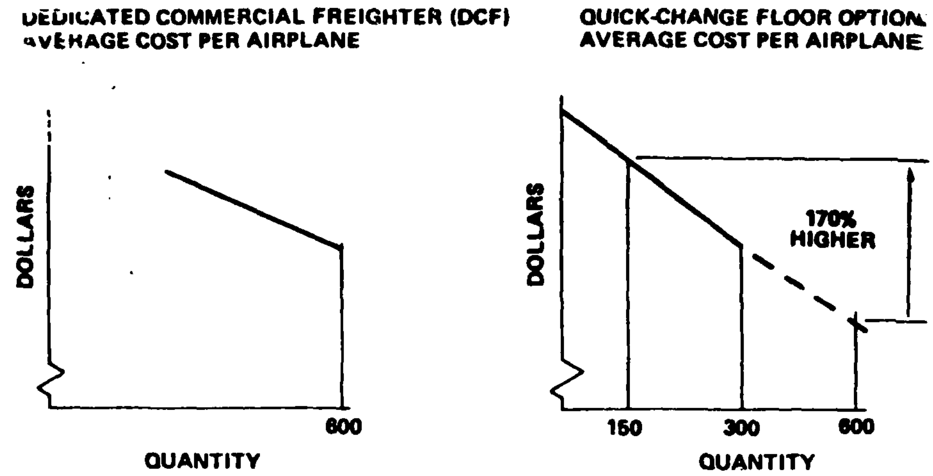


Figure 6.3.7 Commercial Program Prices

• Year of dollars	FY 1978
• Fuel price	$0.42 per gal
• DCF baseline price	Based on a commercial program with total sales > 600
• Cargo density	10 lb per ft^3
• Stacking efficiency	85%
• Direct operating cost (DOC) model	Boeing version of 1967 ATA–international rules
• Depreciation methods	
DOC	Straight line–15 yr to 10% residual
ROI (to the airline)	Sum-of-the-years digits–10 yr for aftertax ROI

Figure 6.3.8 Commercial Economics Ground Rules

7.0 DESIGN OPTIONS EVALUATION

The design options were evaluated by examination of their impact on two contingency scenarios: 1) early reinforcement of the NATO forces, and 2) movement of a mobile force into the Persian Gulf area. Three design option parameters, conversion time, payload and utilization, were evaluated for each option and used in each scenario to determine the CRAF fleet sizes required to augment a minimum organic military force. Mission analysis of fleet requirements for the two scenarios revealed NATO as being the more critical.

The design options were further evaluated by determining the direct operating cost penalties for commercial operation of the Enhanced CRAF airplanes as well as the military life cycle costs for the military organic/CRAF fleet mixes. For this evaluation procedure the number of Enhanced CRAF transports was held constant at 136 and the required organic military fleet to complete the movement was determined.

To establish the basic organic/CRAF fleet mix, a minimum of 100 organic military aircraft was selected to (a) ensure rapid reaction to mobilized contingencies, (b) to initially transport ground support equipment such as mobile loaders, and (c) to provide a reasonable non-mobilized contingency force.

The minimum Enhanced CRAF fleet which meets the NATO movement requirement when employed with the 100 organic military aircraft was determined to be 136. This fleet resulted from use of the passenger module as the design option aircraft(1). When other options were employed, a larger organic military fleet was required in order to compensate for the reduced military payload caused by the Design Options.

7.1 Scenarios and Requirements

Two scenarios were considered for analysis, NATO and the Persian Gulf, Figure 7.1.1. Reinforcement of NATO for the first fourteen days after mobilization places emphasis on mass movement of combat forces from the United States to the Western Germany (FRG)in response to Warsaw Pact

(1) This did not, however, result in a competitive commercial passenger airplane.

aggression. Prepositioning of the heavy equipment of a few Army divisions enables rapid build-up of ground combat forces during the first week when strategic airlift must be concentrated on transporting Air Force fighter wings into the theater. When Air Force units are delivered, movement of the remaining CONUS Army units is initiated.

The Persian Gulf scenario entails moving complete U.S.combat units and their required supporting elements from the CONUS to the critical oil producing areas. The recently announced "100,000 man mobile force" formed the basis for sizing this requirement. The potential combat theater, Saudi Arabia, exemplifies world-wide delivery points where timely airlift is essential because of the lengthy sea line of communication, but is hampered by the limited availability of enroute air bases for aircraft refueling.

7.1.1 NATO Airlift Scenario

Notional onloads and offloads were used to represent the average distances required for NATO airlift support. In Figure 7.1.2, Tinker AFB, Oklahoma, represents the mid-CONUS onload base and Frankfurt, West Germany the offload airport. By air refueling as necessary, the organic military transports can maintain maximum payload efficiency, being limited only by "cube out" from carrying low density cargo. To maintain maximum CRAF payload efficiency, the civil aircraft must be refueled at enroute bases, represented by the East Coast or Goose Bay, Newfoundland. Because the provisions for in-flight refueling were incorporated in the design options, air-refueling was considered as a means of maximizing CRAF payload; however, this feature was not employed after consideration of tanker availability for the CRAF and training/proficiency requirements for civil pilots.

Theater offload without refueling was made to reduce exposure time to combat conditions and to preclude exporting the critical aviation fuel resource from the combat zone. Furthermore, recovery in the United Kingdom enables reconfiguration of aircraft if the mission dictates necessary maintenance before the overwater return trip is initiated. For both military and CRAF aircraft, sufficient range is available for a nonstop return flight to the CONUS onload base.

- NATO reinforcement—early airlift
    - First 2 weeks
    - U.S. pre-position roundout, 20 USAF fighter wings and 2 USA divisions
    - Mobilization plus CRAF
- Persian Gulf
    - Five-week airlift (until sealift)
    - Four divisions, 10 tactical fighter wings (TFW), and support (100,000 men)
    - Supplies for Saudi Arabian forces
    - Limited en route bases
    - Mobilization plus CRAF

Figure 7.1.1 Scenarios

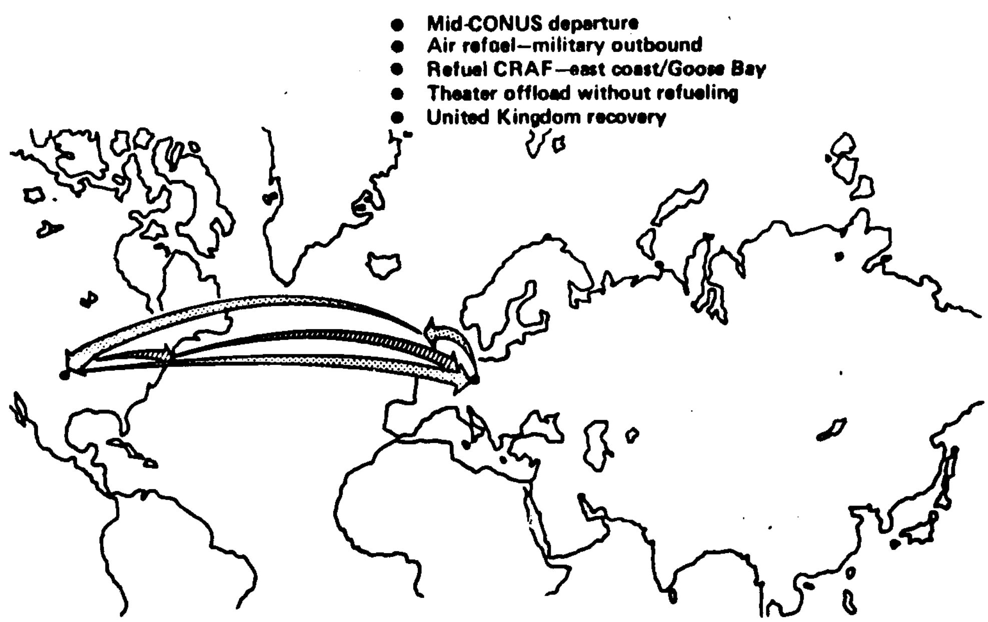


Figure 7.1.2 NATO Airlift Scenario

To size the requirement for the first fourteen days of NATO conflict , the Secretary of Defense's announced goal of reinforcing with five divisions and 60 fighter squadrons in the first ten days established the desired build-up rate. The Army build-up rate of approximately one division each two days was continued by adding two non-prepositioned divisions to complete the fourteen day requirement package. As indicated by Figure 7.1.3, early airlift concentration was initially on movement of the fighter squadrons and then the Army divisions.

Assuming the outsize equipment of 5 1/3 armored and mechanized divisions was prepositioned, the remaining current Army divisional and Air Force fighter wing tonnages project to more than 180,000 tons broken down into cargo categories as shown. These cargo categories were defined using the loadability of current strategic aircraft as the basis. As will be shown in the evaluation which follows, these percentages change when design option aircraft are used to transport the military cargo.

7.1.2 Persian Gulf Scenario

The Persian Gulf scenario represented in Figure 7.1.4 emphasized longer distances and fewer enroute stops than the NATO scenario where the use of Lajes, Azores for enroute refueling of the CRAF airplanes was essential for retaining productive payloads. Effective payloads for Enhanced CRAF aircraft had to be reduced approximately five percent because of the length of the Lajes to Dhahran leg. The organic military aircraft, with the air refueling option, retained full payload capability.

In this scenario, both military and CRAF aircraft refueled at Dhahran after offload and returned to mid-CONUS onload sites without further stops for fuel.

Figure 7.1.5 contains the projected tonnages associated with the Persian Gulf scenario. Using a selected "100,000 man mobile force" as the basis for sizing yielded a total tonnage of 242,000 delivered in the five weeks prior to sealift effectiveness. This force was selected to insert early tactical fighter and ground force up with heavy combat divisions. Generic unit sizes and assumed support tonnages of 50% were used to determine the total requirement. Support of 1,000 tons per day for the Saudi Arabian forces was included.

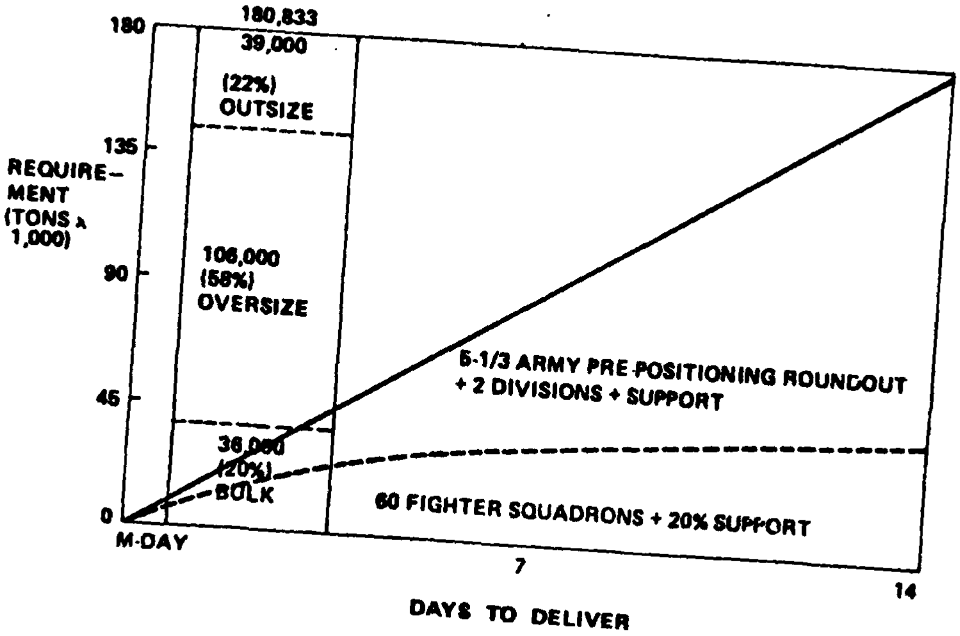


Figure 7.1.3 NATO Movement Requirements

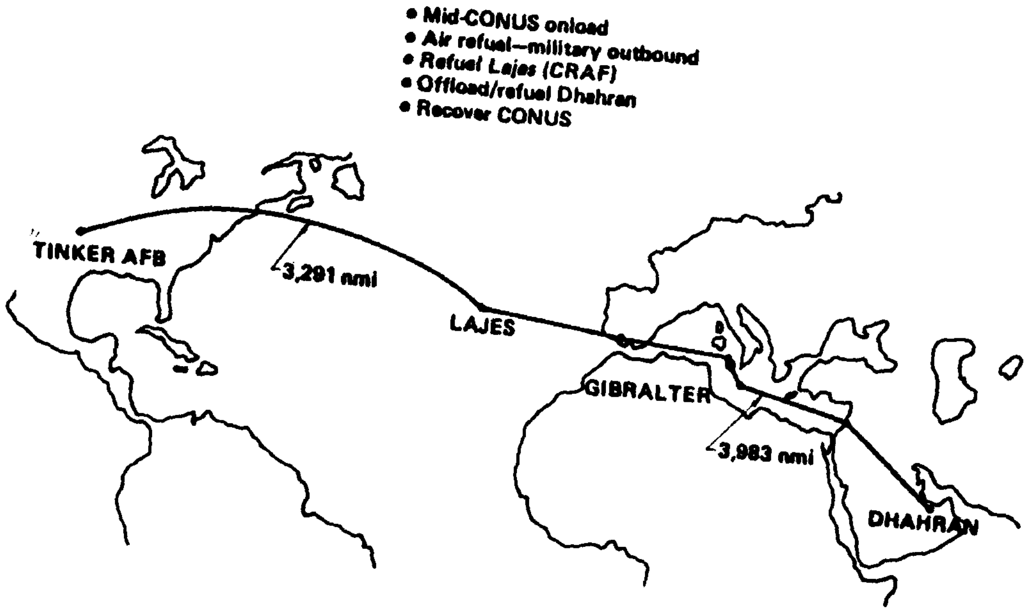


Figure 7.1.4 Persian Gulf Scenario

7.1.3 Loadability of Requirements

Useable airplane cross-section and floor strength are critical design factors for determining military cargo capability, and these factors are used to categorize military cargo requirements. Results of simulated loading of the design aircraft are presented in Figure 7.1.6. Major differences in percentage by weight loadability between aircraft in parts 1 and 2 of the figure reflect a strengthened floor incorporated in design option models. The dedicated commercial freighter, with the commercial floor, is restricted to vehicles weighing approximately 25,000 pounds, resulting in divisional loading capabilities ranging from 28 to 82 percent depending on the type of Division . The same cross-section aircraft, with a military type floor can accommodate up to 98 percent of the Army's equipment. Thus, the term "outsize" is applied to those vehicles not loadable in the design option aircraft with the strengthened floor option. In this study, design options of the dedicated commercial freighter with the strengthened floor were assumed to load 95 percent of all requirements, and those options with increased cross-section features attained 100 percent loadability, as did the military derivative.

7.1.4 Airfield Requirements

The Load Classification Number (LCN) of the Design Options Aircraft was used in evaluating availability of airfields for the NATO and Persian Gulf scenarios. As shown in Figure 7.1.7, the options aircraft are capable of operating at airfields which accommodate the C-141 and Boeing 747. The dotted line on the -100/-200 line indicates gross weight up to 588,000 pounds resulting from operation at a 2.25 g load factor.

In the NATO scenario, deleting the requirement for refueling at the offload airport enables the aircraft to operate at gross weights corresponding to the lower portion of the LCN line. The low gross weights also reduce runway length requirements below the design 8000 foot design standard. In the West Germany/BENELUX areas, there are about 50 airports with facilities suitable to this aircraft and with a minimum of 6000 feet, LCN greater than 38 and runway width of at least 148 feet. In the Saudi Arabia theater, there are 19 airports suitable for military operation, all with runway lengths of 10,000 feet or greater.

Unit	Tonnage (x 1,000)	Passengers (x 1,000)
10 tactical fighter wings	12	16
Airborne division	15	15
Airmobile division	15	18
Mechanized division	48	18
Mechanized division	48	18
Base totals	138	85
+50% initial support increment and resupply	69	17 (20%)
Total U.S.A.	207	102
Support for allies (1,000 t/day)	35	
Total requirements	242	

*Based on Secretary of Defense "100,000-man mobile force."

Figure 7.1.5 Persian Gulf Requirements

1. By weight restriction—25,000-lb combat-loaded vehicles (including trailers), 134-in height

Armored division	Mechanized division	Infantry division	Airborne division	Airmobile division
28	31	48	81	82

2. By door height limitation (4-in clearance), no weight restriction

	Door height (in)	Armored division	Mechanized division	Infantry division	Airborne division	Airmobile division
	126	57	64	76	95	91
	133	61	67	79	96	94
IAV design	134	93	93	90	96	94
Military floor	138	97	98	96	97	96

Major vehicles not loaded at 133 in:

Vehicle	Weight (lb)	Number per division type
M-60 tank	111,600	324/armored, 216/mechanized, 54/infantry
M-109 A1 howitzer	53,000	54/armored, 54/mechanized
M-548 cargo carrier	34,400	66/armored, 66/mechanized, 4/infantry
CH-47 helicopter	23,448	48/airmobile

* Substitute airlift loading model, Boeing Aerospace Company.

Figure 7.1.6 Army Vehicle Loading (Percent by Weight)

7.2 Design Option Parameters

To determine the fleet size required for satisfying the scenarios studied, three major parameters, conversion time, payload, load and unload times or utilization were evaluated as to changes resulting from addition to various design features Figure 7.2.1. These parameters form the basis for measuring the capability of the option aircraft to perform the designated mission. If the required tonnage to be delivered is held constant, differences in conversion time, payload and utilization produce different numbers of aircraft for the same requirement.

Conversion time, for example, determines the number of days the aircraft is available for the scenario and results in a daily tonnage movement requirement. When matched with the capability of the aircraft, determined by payload and utilization rates, the fleet size of a particular option is calculated.

7.2.1 Cargo Handling Time

In Figure 7.2.2, the elements of loading and unloading operations are compared. Major elements are vehicle tie down/untie, load/unload, ramp and kneel/unkneel times. Tie down of vehicles during loading and kneel/unkneel time during unloading are the most time consuming factors. The kneel/unkneel operations which includes preparatory actions during loading are also relatively time consuming. Therefore, as shown by the reduced time when kneeling is not included, ground times can be reduced by about one-half hour if an alternate method for compensating for deck height is employed.

For this study, the mobile transporter-loader was evaluated against kneeling/on board ramp operations. Assuming that the transporter loader can be made efficient enough to provide drive on/off capability for transported vehicles, deletion of the requirement for kneeling and unkneeling results in a savings in ground time which effectively reduces mission cycle time.

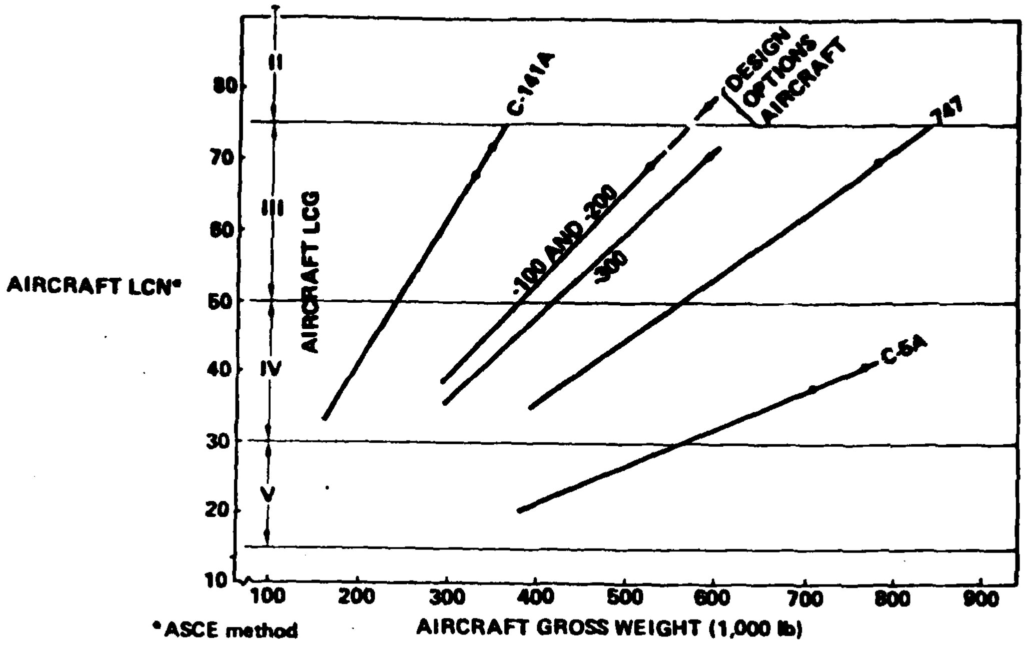


Figure 7.1.7 Aircraft LCN Comparisons

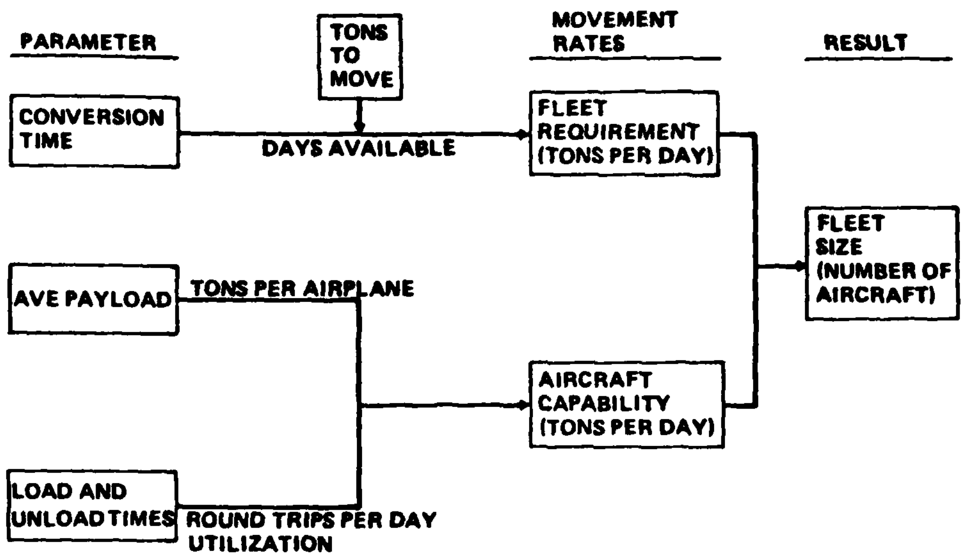


Figure 7.2.1 Relationship of Design Option Parameters

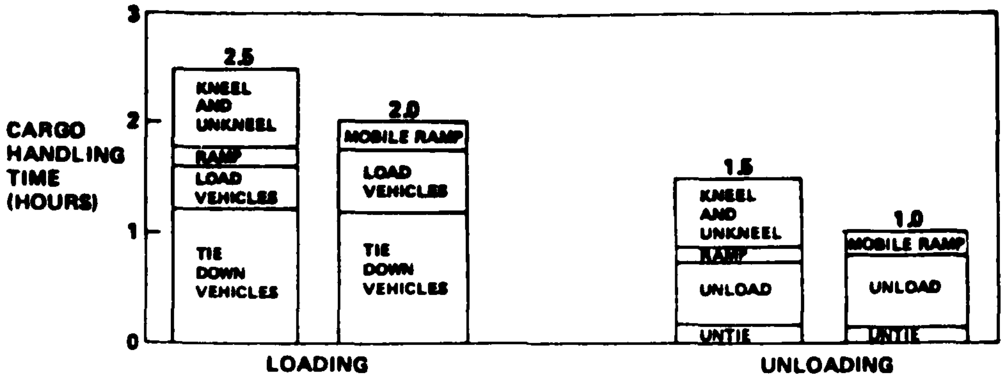


Figure 7.2.2 Cargo Handling Time

Operations activities			
Function	Crew size	Required man-hours	Conversion flow-hours*
• Kit conversion crew			
• Shop	35	448	16
• Mechanic			
• Rigger			
• Electronics technician			
• Electrician			
• Plumber			
• Coordination	2	24	12
• Stores and expediting	2	24	12
• Quality assurance	4	48	12
• Dedicated project shop support			
Total	43	544	16

*Separate functions accomplished concurrently

Assumptions:
1. Three-shift basis (24 hr/d)
2. Kits available, ready for installation
3. Airline facility, equipment, and personnel on site
4. Conversion crew is dedicated and high skill level

Figure 7.2.3 CRAF Airplane Conversion - Quick Change Floor

7.2.2 Enhanced CRAF Airplane Conversion

Since the time needed to convert each option to its military configuration has a major impact on mission capability, detailed analysis was made to determine conversion times for each option. Figure 7.2.3 summarizes detailed analysis of the operations activities required for converting the CRAF commercial freighter into the Quick Change Floor Option. The numbers of kit conversions crews, total manhours and conversion flow-hours for installing the strengthened floor capable of supporting cargo as heavy as the M-60 tank are listed by work function. Since availability of the airplane for the mission is dependent on the required conversion time, it is assumed that skilled crews are available for immediate kit installation.

A conversion crew of 43 expending 544 hours is required for each aircraft to install the quick-change floor and its associated features. Since many of the operations are accomplished concurrently, the pacing item, shop work for floor installation, determines the conversion flow time of 16 hours per airplane for this option.

In Figure 7.2.4 required times for the most extensive conversion of all the options is depicted. The lowered military floor option includes most of the features incorporated into other options and thus requires the longest time. A crew size of 103 will expend 2,562 hours with a total flow time of 93 hours.

The conversion times of nine of the options are compared in Figure 7.2.5. Three of the options, folding on-board ramp, side cargo door and swing tail meet the study goal conversion time of 48 hours. Assuming sufficient facilities and crews to handle all required conversions concurrently, a fleet of CRAF airplanes with these options could be available within two days.

The quick change floor and stabilizing struts options require the least number of conversion hours while the lowered floor and cargo pod options are the most time consuming.

Operations activities			
Function	Crew size	Required man-hours	Conversion flow-hours*
• Kit conversion crew			
• Shop	71	1,756	93
• Mechanic			
• Rigger			
• Electronics technician			
• Electrician			
• Plumber			
• Coordination	9	230	93
• Stores and expediting	10	228	93
• Quality assurance	13	346	93
• Dedicated project shop support			
Total	103	2,562	93

*Separate functions accomplished concurrently

Assumptions:
1. Three-shift basis (24 hr/d)
2. Kits available, ready for installation
3. Airline facility, equipment, and personnel on site
4. Conversion crew is dedicated and high skill level

Figure 7.2.4 CRAF Aircraft Conversion - Lowered Military Floor

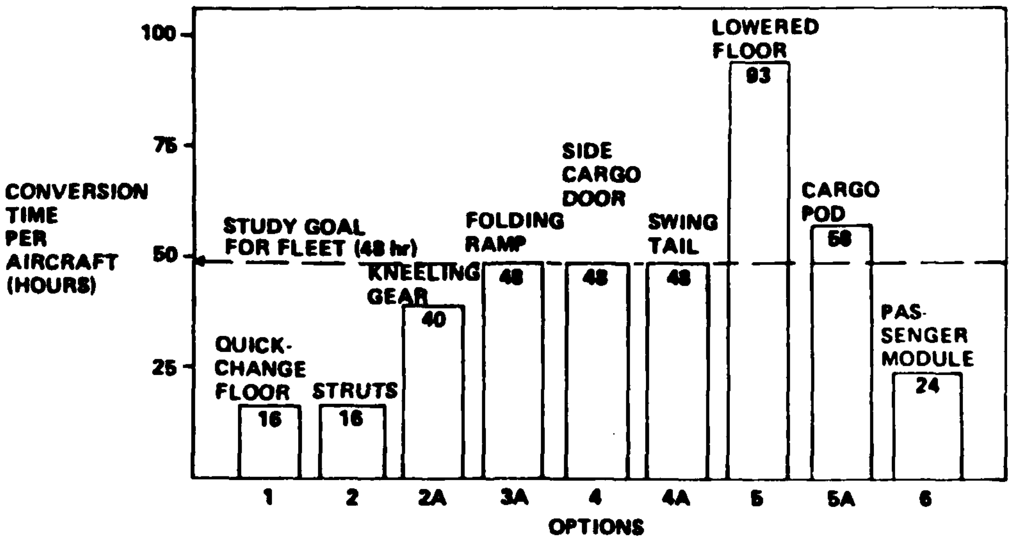


Figure 7.2.5 Design Options Conversion Times

The conversion times reflect relative complexity of installed features and therefore were used in the analysis as a basis for aircraft availability.

7.2.3 Effect of Conversion Time on Required Movement Rate - NATO

The effect of introducing Enhanced CRAF conversion time into the NATO scenario is shown in Figure 7.2.6. With no conversion requirement, the military fleet is applied to the scenario immediately after mobilization (M-day). Initial slope of the line results from a lower utilization rate during the first two days as the fleet builds up to a "steady state" scenario operation. A constant delivery rate was then maintained for the remainder of the delivery days.

An all CRAF fleet required additional delay because of conversion times and necessitated higher daily movement rates to achieve the required total deployment in the fourteen day period.

A mix of organic military and CRAF airplanes produced a daily movement rate as shown by the middle line. The result was a total fleet larger than an all military fleet, but considerably smaller than that required for an all CRAF delivery.

Mission effectiveness for each design option is then measured by comparing required fleet sizes to move the required tonnage in the time allocated.

7.2.4 Effect of Movement Parameters on CRAF Fleet Size

In Figure 7.2.7, trades showing the impact of operating weight, ground time and conversion time on Enhanced CRAF fleet size for a NATO scenario are shown. Changes in operating weight, which are directly equivalent to payload changes, have the greatest impact on numbers of airplanes required for the same movement capability. To show the effect on fleet size the number of aircraft required for a unit change and the value of one aircraft in terms of each parameter are also shown.

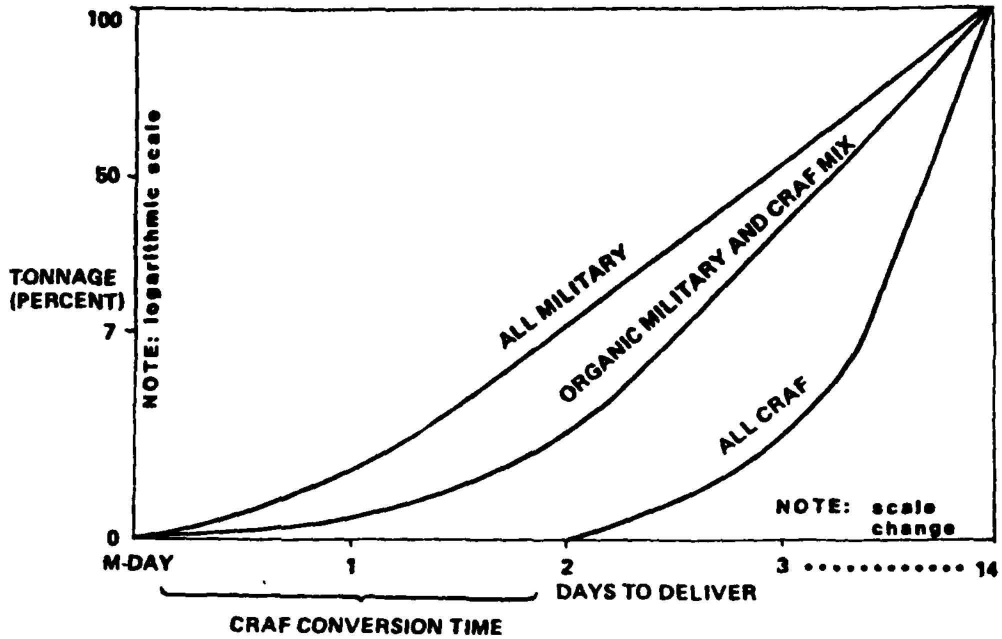


Figure 7.2.6 Effect of Conversion Time on Required Movement Rate - NATO

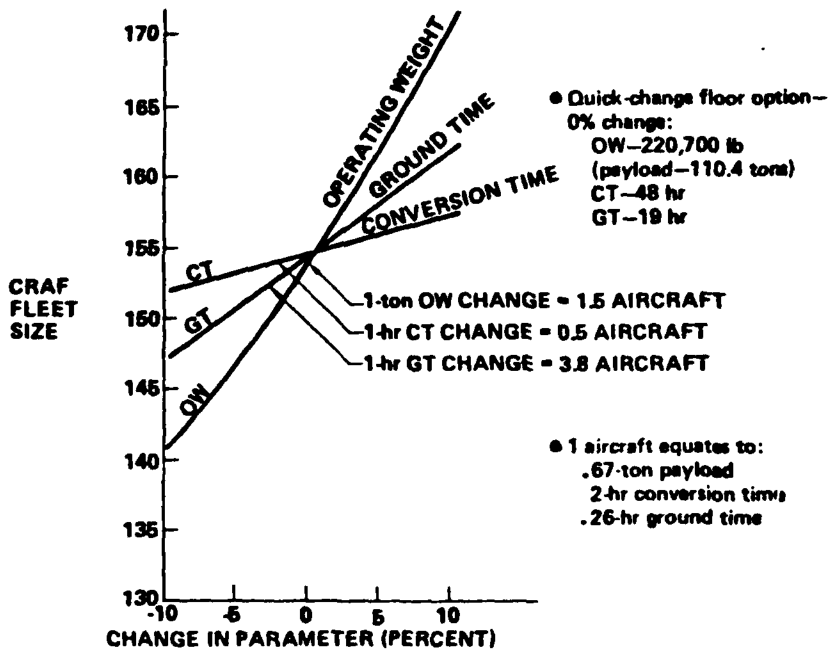


Figure 7.2.7 Effect of Movement Parameters on CRAF Fleet Size - NATO Scenario

Ground time was impacted a maximum of one hour in the NATO scenario, resulting in a difference of about four aircraft. Differences in operating weight and conversion times produced by adding design option features resulted in significant fleet size changes. For example, an increase of five tons in operating weight requires eight more aircraft, and one additional day conversion time requires twelve more aircraft to deliver the same tonnage.

7.3 Mission Cost Effectiveness

In Figure 7.3.1 assignments of passenger movement rates and cargo tonnages are shown for the NATO scenario. Initial assignment of tonnage to a proposed military organic fleet was necessary to insure that some degree of capability was available while CRAF airplanes were being converted. The initial sizing was derived by assuming of the capability of the current fleet for a NATO movement, approximately 5700 tons per day was replaced. Moving 5730 tons for the 13 day period resulted in 74,100 tons of cargo moved, including the 9000 tons of cargo considered outsized to the CRAF options (5 percent of the total) that do not have the lowered floor feature.

Movement of 74,100 tons by military organic aircraft required 159,700 tons to be carried by CRAF. 21,133 tons of this are bulk cargo not requiring Enhanced CRAF Design Options. Thus this cargo was assumed to be moved by commercial freighters without requiring conversion time. The result was a requirement of 1620 tons per day equating to 33 commercial freighters. Subtracting the bulk requirement left a requirement for the Enhanced CRAF of 85,600 tons.

Passenger movement, equating to a current capability of 33,929 per day, is handled by 111 Dedicated Commercial Passenger derivative of the design option aircraft.

7.3.1 Military/CRAF Mixes - NATO

The fleet size for each design option was determined by applying its capability to the Enhanced CRAF requirement of 85,600 tons in the 14 day

CARGO			PASSENGERS
Requirement (180,833 tons)	**Capability (movement rate)**	**Number of aircraft**	**Movement rate**
85,600 tons	85,600 tons divided by days available	Design option aircraft fleet size	33,929 passengers per day
21,133 tons (bulk)	1,620 tons per day, 13 days	33 commercial freighters	111 commercial passenger aircraft
74,100 tons (Outsize, 9000 tons)	5,730 tons per day, 13 days	100 dedicated military	

Figure 7.3.1 NATO Cargo and Passenger Assignment

Concept	1. Quick-change floor	2. Struts	2A. Kneeling gear	3A. Onboard ramp	4. Side door	4A. Swing tail	5. Lowered floor	5A. Cargo pod	6. Passenger module	6A. Convertible freighter
Mission parameters										
• Maximum payload[a] Tons	110.4	103.1	108.8	106.4	103.5	103.4	112.9	98.9	118.3	103.7
• Conversion time Hours	16	16	40	48	48	48	93	58	24	24
• Flight time/cycle Hours	20.4	20.4	20.4	20.4	20.4	20.4	20.4	20.4	20.4	20.4
• Ground time/cycle Hours	19	20	20	20	20	20	20	19	20	20
Productivity analysis										
• Utilization rate Hours	12.4	12.1	12.1	12.1	12.1	12.1	12.1	12.4	12.1	12.1
• Trips/day	0.61	0.59	0.59	0.59	0.59	0.59	0.59	0.61	0.59	0.59
• Tons/day/aircraft	50.4	45.9	48.5	47.4	46.1	46.1	50.3	45.2	52.7	46.2
• CRAF Fleet size	138	152	156	165	169	169	187	180	136	156

[a]Average payload = Maximum payload x 0.75

Figure 7.3.2 Design Options Operational Data and CRAF Fleet Size - NATO Scenario

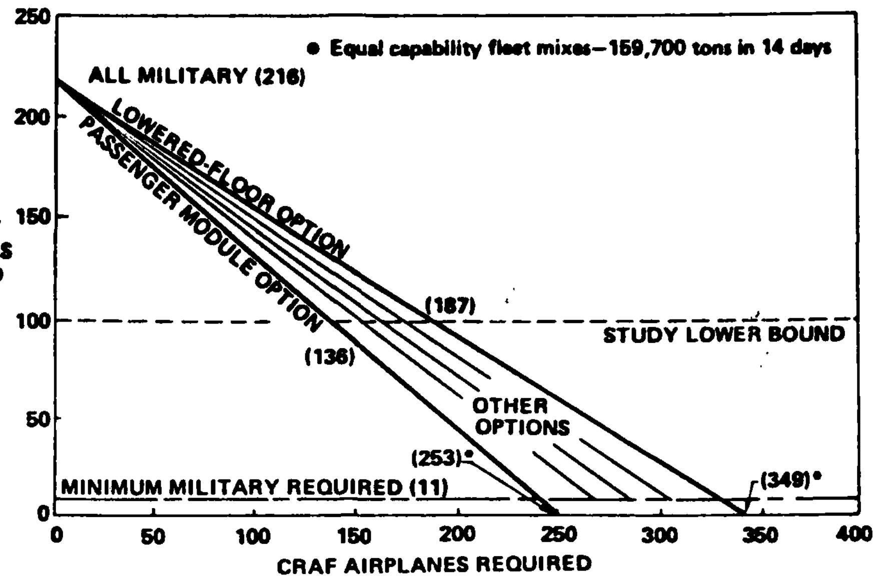
schedule. Fleet sizes ranging from 136 for the passenger module to 187 for the lowered floor were required because of differences in payload, ground time and conversion time. Operational data for each of the options are summarized in Figure 7.3.2.

Two of the options are highlighted to illustrate the factors responsible for different fleet sizes. Options 1 and 5 have similar tons per day capability (50.4/50.3) but result in a difference of 49 aircraft required (138 versus 187). Inspection of the factors that yield these fleet requirements reveals that the principal cause of this difference is conversion times (16 hours for concept 1 and 93 hours for concept 5). The Quick Change Floor Option, because of short conversion time and mission cycle hours is the most mission effective concept.

Figure 7.3.3 illustrates the range of aircraft that could be employed to move the 160,000 tons not carried by the dedicated commercial freighter. If an all military fleet were employed, 216 military derivatives would be required. Various mixes of military and CRAF airplanes, or an all CRAF fleet could be used to move the entire requirement. The passenger module option could move the requirement with 253 aircraft while the lowered floor option would require 349. With non-increased cross section options a minimum organic fleet of 11 aircraft were required to carry the 9000 tons of outsize that are not loadable in the CRAF airplane.

For the study a minimum of 100 military aircraft were used to insure rapid reaction to mobilized contingencies, initial transport of mobile loaders and to provide a non-mobilized contingency capability. For equal capability fleet mixes, the number of CRAF airplanes needed to satisfy the movement requirement is determined for each option.

In Figure 7.3.4 the area encompassing the military lower bound was expanded to show the relationship of all the options in terms of fleet size. The minimum number of Enhanced CRAF aircraft to correspond with 100 organic military is 136 of the passenger module aircraft. The next lowest option is the quick-change floor. Lengthy conversion time causes



*Passenger module and lowered floor options carry all military cargo; other options carry 95% of cargo.

Figure 7.3.3 CRAF Augmentation - NATO

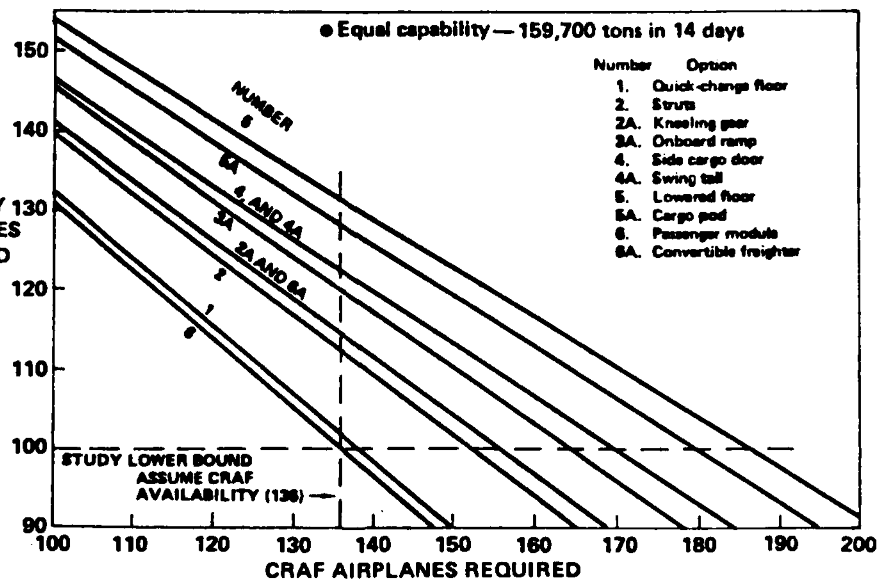


Figure 7.3.4 Military CRAF Mixes - NATO Scenario

the lowered floor option to require the largest fleet thereby making it the least effective option.

To illustrate the impact of Enhanced CRAF fleet size on required military fleet size the minimum number of 136 was selected as the basic civil fleet size available for CRAF conversion. All options were then limited to 136 aircraft to determine the increase in military fleet necessary to satisfy the remaining requirement. For example, 123 organic military aircraft would be needed to complete the movement if only 136 of the side cargo door and swing tail options (4, 4A) were available.

This also provided a basis for determining differences in military life cycle costing for the required fleet.

7.3.2 Military/CRAF Mixes - Persian Gulf Scenario

The design option aircraft were applied to the Persian Gulf scenario requiring a delivery of 242,000 tons in 35 days, Figure 7.3.5. As with the NATO scenario, the best option in terms of CRAF airplanes required with 100 military organic aircraft was the passenger module. However, other options differed in ranking when compared with the NATO scenario results. The poorest option was the cargo pod because of low relative payloads, while the lowered floor increased in effectiveness because the lengthy conversion time did not impact fleet size as much over the longer delivery period. Again the quick-change floor was next best, after the passenger module.

A minimum of 106 Enhanced CRAF airplanes were required to complete the tonnage movement. In this scenario, no commercial freighters were employed because of the nature of the requirement which was composed of a higher percentage of heavy equipment, and operations into airfields conducive more to military operations.

7.3.3 Summary of Design Option Effects

The total fleet sizes for various options are summarized in Figure 7.3.6. If no Enhanced CRAF were used, the military would need 244 UE

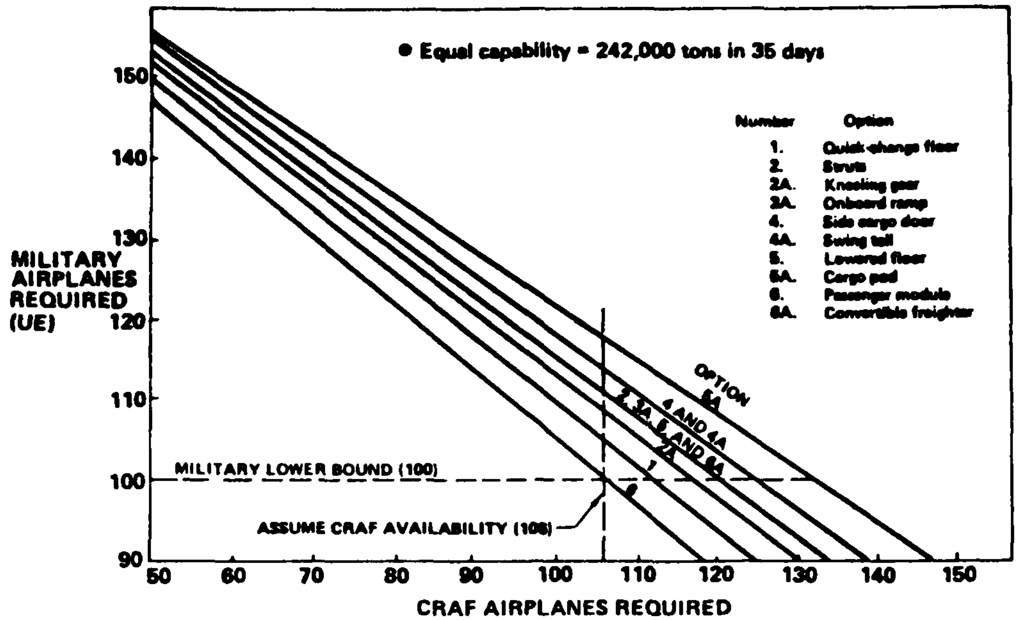


Figure 7.3.5 Military CRAF Mixes - Persian Gulf Scenario

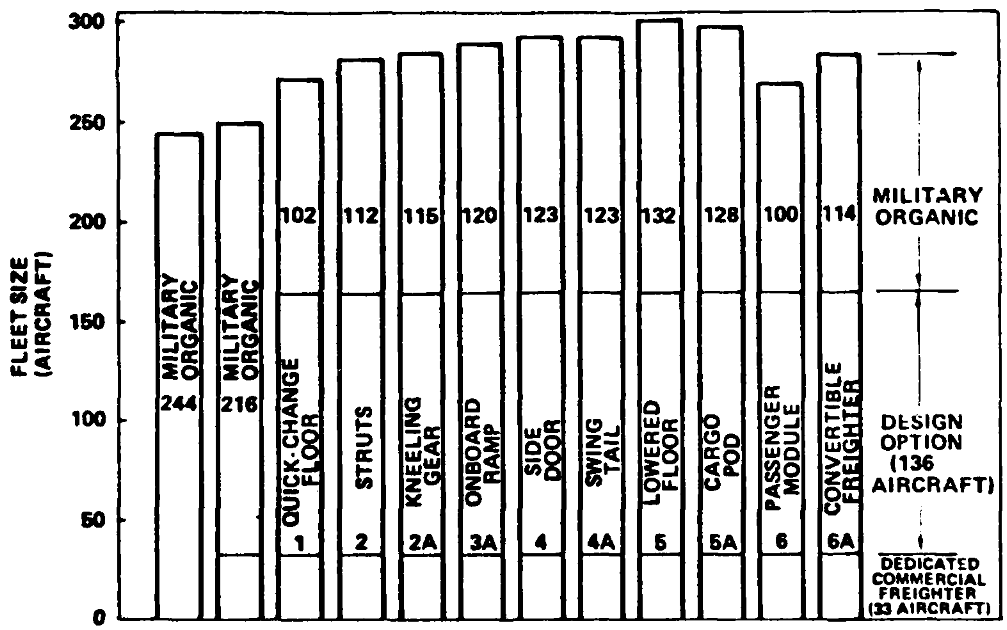


Figure 7.3.6 Design Options Effects on Total Fleet Size - NATO Scenario

aircraft to move the entire 181,000 ton requirement,. Use of 33 dedicated commercial freighters decreases the required military fleet to 216.

As noted previously, a figure of 136 Enhanced CRAF aircraft was determined as the minimum number required to supplement a military fleet of 100. For other options, additional organic military aircraft are required to maintain the same capability. The military fleet for other options ranges from 102 for the quick-change floor to 132 for the lowered floor.

These military fleets were used to cost the capability required to respond to the NATO scenario.

To determine the minimum fleet size required for overall contingency responsiveness, the Persian Gulf scenario was exercised using the NATO fleet previously sized. In all cases the Persian Gulf scenario required less than the full capability of the NATO fleet. This is illustrated in Figure 7.3.7.

Except for Option 1 (which required 81 percent), 78 percent of the Enhanced CRAF fleet and 85 percent to 100 percent of the military fleet required for NATO will move the Persian Gulf tonnage in 35 days. Since the NATO scenario is the more demanding task, cost analysis was concentrated on NATO fleet sizes.

7.3.4 NATO Scenario Life Cycle Costs

The life cycle cost for twenty years of the organic military aircraft plus the conversion kits required for CRAF aircraft are shown in Figure 7.3.8. These costs can be compared with those associated with an all military buy of 216 unit equipped aircraft required to move approximately 160,000 tons in the 14 day NATO scenario.

In the legend, a breakdown of the elements comprising the total costs is listed. Included are acquisition cost for the indicated number of

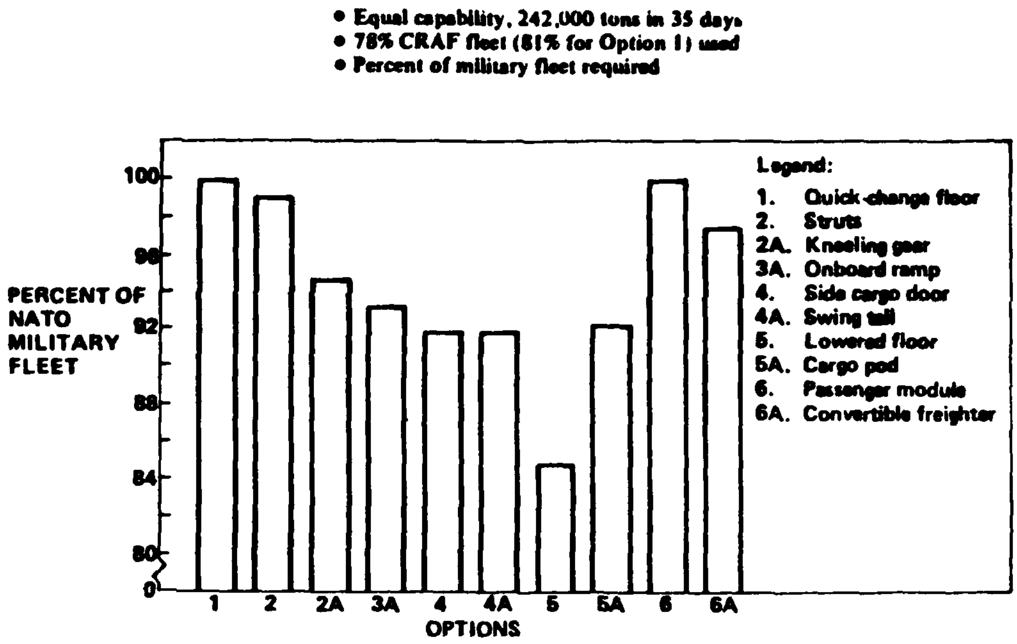


Figure 7.3.7 Persian Gulf Scenario with NATO Fleet

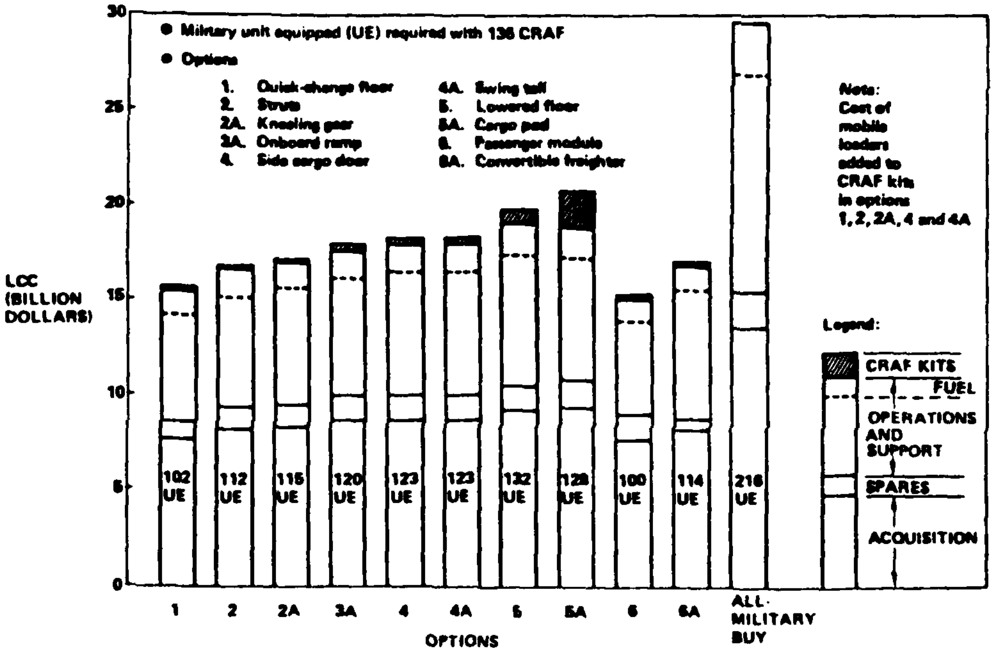


Figure 7.3.8 Military Life Cycle (LCC) - NATO

organic aircraft, a spares buy of 15 percent of the acquisition cost, and operations and support costs (including fuel)for the UE fleet. CRAF kits for the 136 commercial freighters include mobile transporter loaders needed for options that do not have the on-board ramp feature.

The life cycle cost totals are heavily influenced by the size of the required organic fleet. Only Option 5A, the cargo pod, has a higher total cost than UE organic numbers indicate because of relatively high kit costs. The passenger module, closely followed by the Quick Change Floor, is the best selection when only military effectiveness and costs are considered. However, payment to the commercial operators for weight penalties associated with commercial use of this option are not included. These penalties are discussed in the evaluations of direct operating costs and return on investment for each option in Section 7.4.

7.4 Commercial Cost Impact

The impact on commercial operations of adding the design features and SCAR weight associated with various options can be quantified in terms of direct operating cost (DOC) and return on investment (ROI).

7.4.1 Direct Operating Cost Elements - Freighter Aircraft

The elements of direct operating costs associated with addition of design features are compared with those of the dedicated freighter in Figure 7.4.1. The commercial freighter, at 2,000 nautical mile trip lengths, operates at a cost of 6.1 cents per available ton mile.

When design features are added, both the increased cost of the CRAF airplane and the smaller maximum payload (due to SCAR weight) produce higher operating costs.

The option with the lowest operating cost is the quick-change floor as this option has a smaller price differential as well as a low weight penalty. The highest operating cost, 7.9 cents, occurs for the convertible freighter option because of additional cost penalties for both commercial and CRAF modifications.

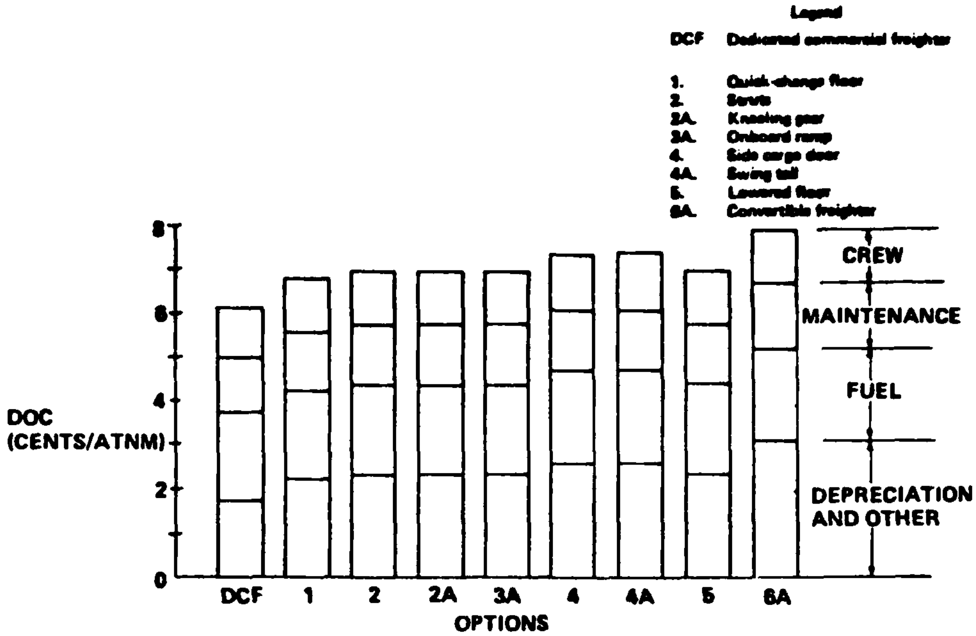


Figure 7.4.1 Direct Operating Cost Elements - Freighter Aircraft (2,000 nmi Trip Length)

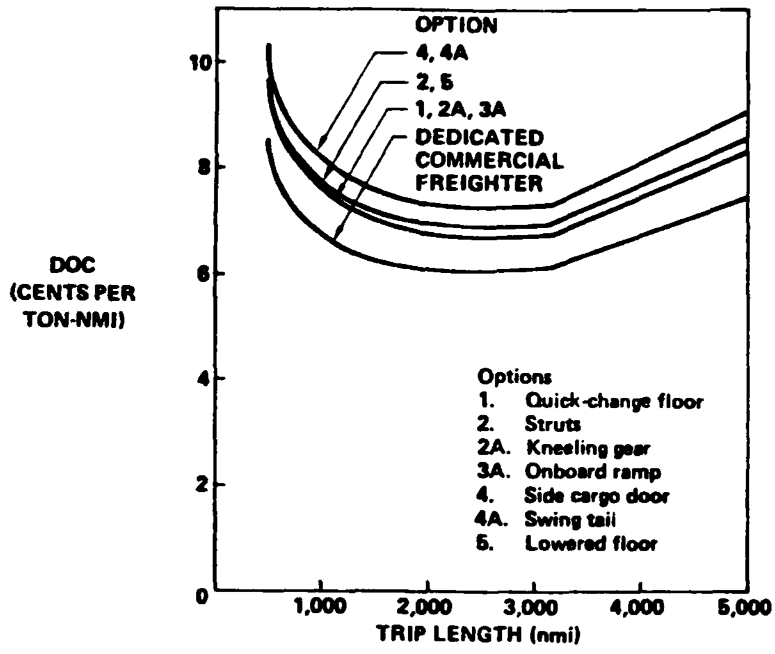


Figure 7.4.2 Trip Length Effect on Direct Operating Cost (DOC)

In Figure 7.4.2, direct operating costs for a range of trip lengths are compared with those of the dedicated commercial freighter. The lowest operating costs are for trip lengths ranging from ATA ranges of 1500 to the 3140 miles. Options 1, 2A and 3A produce the lowest D.O.C's after the dedicated commercial freighter.

The average DOC's of the side cargo door and swing tail options are about 20 percent more than those of the dedicated commercial freighter, primarily because of the increased cost of the CRAF airplane and the reduced payloads available.

7.4.2 Return on Investment - Freighter Aircraft

A measure of the relative discounted cash flow return on investments (ROI's) of the design option aircraft reveals penalties similar to those pertaining to direct operating costs, Figure 7.4.3. The ROI's of Enhanced CRAF option freighters are lower than the dedicated freighter because of the following:

1. Higher purchase prices.
2. Higher DOC elements, such as maintenance, fuel and insurance.
3. Potential revenue is reduced for any given load factor (smaller maximum payload availability).

Projected ROI's with constant 70-ton payloads and for 70 percent load factors are also shown in Figure 7.4.3. The two factors are equal for the dedicated freighter because 70 percent load factor represents a 70-ton payload. The two values shown for various options illustrate ROI extremes. In reality, neither value would be valid for commercial operations because of the frequency of payload demand. Actual ROI will be closer to the 70-ton payload figure since few aircraft loads will approach the maximum available.

ROI penalties of about 35 percent are incurred with the heavier options, such as for the convertible freighter.

7.4.3 Passenger Aircraft DOC and ROI

Passenger aircraft penalties are also measured by direct operating cost and return on investment. DOC is measured in cents/available seat nautical mile and ROI in percent. In Figure 7.4.4 passenger versions of the baseline airplane are compared.

The lowest DOC penalty for cargo options in passenger aircraft is incurred by the cargo pod aircraft because such features as strengthened floor and gear modifications are not required in the basic commercial version of the aircraft.

Highest operating cost penalty results from the passenger module due to high weight and a decrease of 97 available seats when modules are installed.

A review of ROI's for cargo capable version of the passenger aircraft reveals similar results. The greatest penalty is with the passenger module, mostly due to the large reduction in passenger seat availability. The best cost option is the cargo pod.

7.5 Evaluation Summary

Comparison is made of relative military and commercial operations costs for the established NATO airlift force in this study. CRAF military design options are grouped as freighter and passenger aircraft.

7.5.1 Summary Evaluation - Freighter Aircraft

The design goal for CRAF options is established by the minimum LCC and DOC for the required organic and Enhanced CRAF forces, as shown in Figure 7.5.1. The vertical dashed line represents military LCC if 136 dedicated commercial freighters were militarily fully capable without the need for conversion options. The horizontal dashed line represents the DOC where there is no weight penalty for military capability - either a basic DCF or an all organic buy and no Enhanced CRAF buy. Both options are obviously unrealistic and represent design limits.

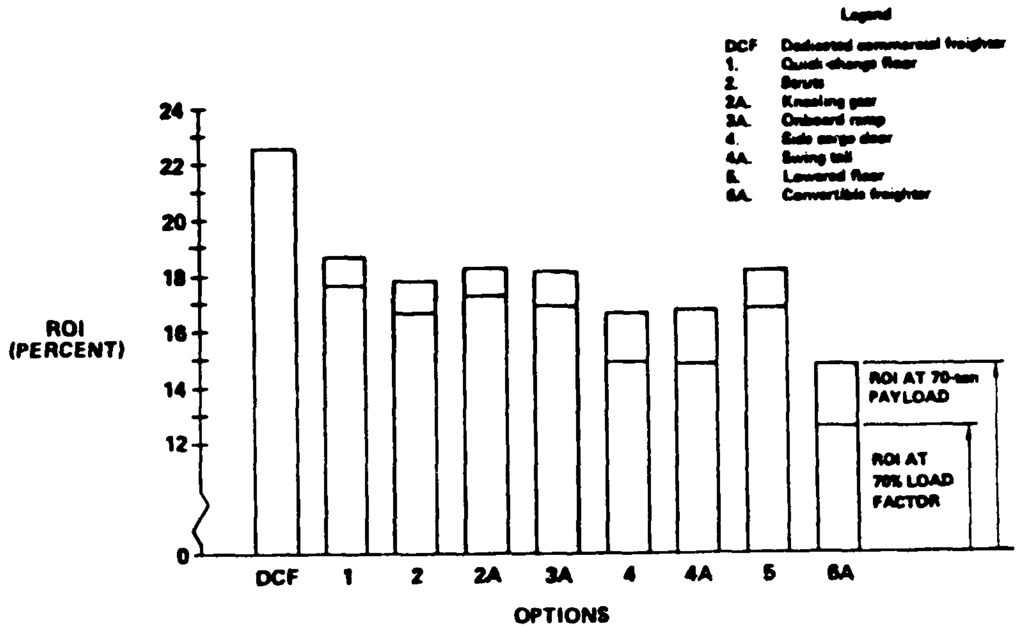


Figure 7.4.3 Return on Investment - Freighter Aircraft (2,000 nmi Trip Length)

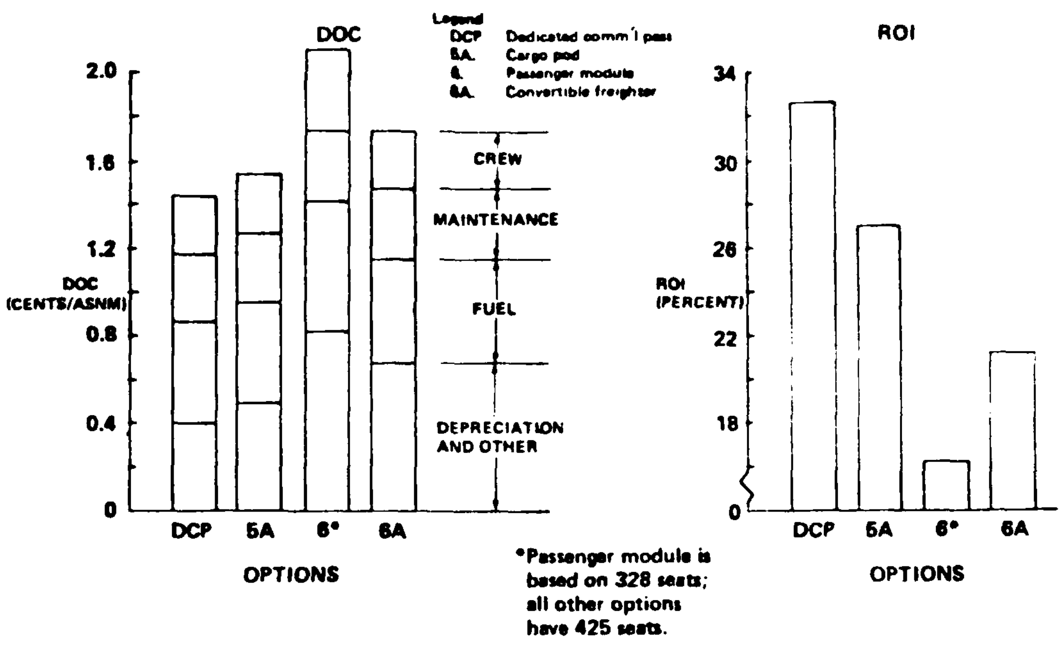


Figure 7.4.4 Direct Operating Cost (DOC) and Return on Investment (ROI) - Passenger Aircraft

The best design options are grouped around the quick change floor option. The quick-change floor is least costly to both military and commercial operations. Adding further military mission flexibility to the Enhanced CRAF options increases cost to both sectors. Options 3A, the onboard ramp, and 5 lowered floor, provides the most flexibility. The onboard ramp eliminates the need for positioning ground loaders and enhances world-wide deployment capability. The lowered floor makes the Enhanced CRAF airplane more nearly like the military freighter if the capability to carry all military equipment is desired. Other design options are either too costly or add little military capability beyond that of these three options.

Overall, the chart illustrates that the minimum change necessary to provide a strengthened floor and loading/unloading capability is the best choice. It highlights cost-effectiveness of civil/military design compatibility and maximum use of civil transports for military emergency operations.

From a pure cost viewpoint, the Dedicated Commercial Freighter (DCF) presents an extremely attractive option because no commercial penalties are imposed. If the freighter were fully utilized without regard for its combat equipment capability, low LCC's could result. However, military flexibility would necessarily be compromised. Selective loading would be required in this case, wherein each aircraft would be limited to certain lighter military equipment, and heavy cargo would require the use of organic military aircraft. The ability to maintain unit integrity and a balance deployment of forces would be questionable.

From a Life Cycle Cost viewpoint, all options are better than buying an all organic fleet, represented by the Dedicated Military Freighter (DMF) with a life cycle cost of nearly $30 billion.

7.5.2 Summary Evaluation - Passenger Aircraft

An evaluation of commercial passenger aircraft with an option for Enhanced CRAF is summarized in Figure 7.5.2. The design goal

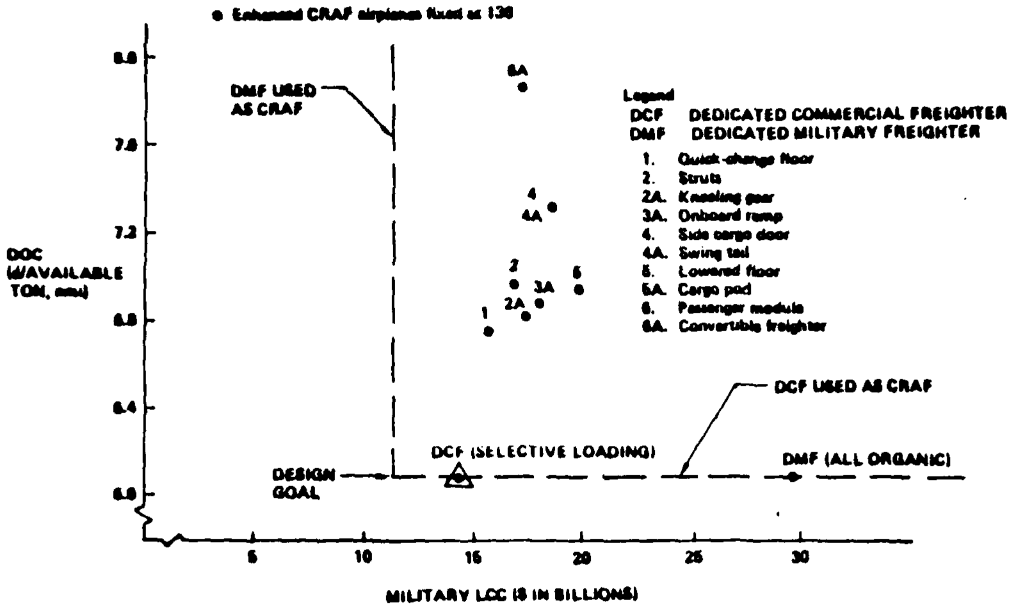


Figure 7.5.1 Design Options Summary Evaluation - Freighter Aircraft

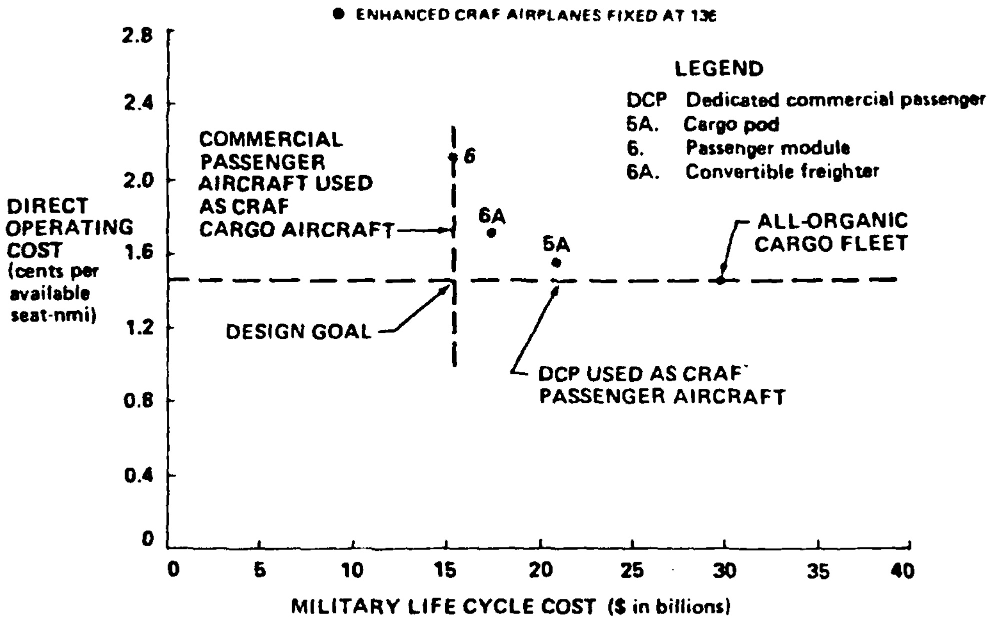


Figure 7.5.2 Design Options Summary Evaluation - Passenger Aircraft

is derived by the intersection of lines representing lowest DOC's and LCC's. Lowest DOC is for the Dedicated Commercial Passenger aircraft and the Dedicated Military Freighter. Lowest LCC's result from the case where the commercial passenger aircraft (passenger module option) is used as a CRAF cargo aircraft.

From a DOC standpoint, the cargo pod incurs a small penalty with a relatively low LCC when compared to an all-organic cargo fleet. Other options reduce the LCC but have attendant high DOC penalties.

As with the freighter aircraft, no allowance was made for loss of revenue due to the operating penalties.

8.0 CONCLUSIONS AND RECOMMENDATIONS

Although establishing the feasibility of commercial-military commonality in transport design was not an objective of the study, the conclusion that a commercial freighter can indeed be used beneficially as a productive military transport seems clear. Much less clear is the need for a new commercial freighter in view of the capability of current aircraft. The conclusions of IADS-77, now substantiated by the CLASS study, Reference 8.1, is that advanced composite primary structure is a prerequisite for initiation of an IAV.

Several of the design options appear quite attractive from the point of view of low commercial penalty and high military benefit. This is especially true for the quick change floor option utilizing the Mobile Loader. In fact, it appears that use of the uncompromised DCF, but with selective military loading preprogrammed to optimize unit payloads, can provide a major portion of the airlift with only a minor increase in the organic fleet.

The military benefit of CRAF is well defined. Achievement of carrier participation is the remaining requirement, involving operational issues and incentive agreements, among others.

Depending on the level of military capability required, commercial costs for the Design Options can range from zero to significant. The issue is how much military capability is needed in CRAF if an organic fleet exists.

The convertible passenger airplane with provisions to convert to an Enhanced CRAF Freighter is an attractive Design Option. However, because it incurs penalties in both commercial passenger and Enhanced CRAF operation - its cost may show it to a disadvantage on a comparative basis. None of the drive through options appeared to provide a cost effective capability, largely due to a lack of improved military benefit which can be attributed to "drive through."

One of the most pervasive influences in the study was the impact of the Enhanced CRAF provisions on the cost of the Design Options airplanes. Commercial pricing was used for both the baseline airplane and the provisions. However, because the CRAF provisions were developed and procured on a small unit buy relative to the baseline airplane - roughly 6 to 1 - the relative cost of the CRAF provisions are high, and significantly influence the results.

As a result a general trend which appears to be emerging is that the baseline design should be changed as little as possible to minimize the cost of the CRAF features while providing the military with an adequate emergency capability to augment the organic fleet. All study conclusions are summarized on Figure 8.1.

It is recommended that in order to provide the technology development for IAV defined in the MAC Statement of Need (reference 9.1), the Air Force and NASA should expedite the development of advanced structures necessary to make the concept economically attractive to carriers.

In general, a number of the design options which look attractive should be given hardware validation to substantiate conclusions arrived at in this study. The overall recommendations are shown on Figure 8.2.

1. Commercial-military commonality still appears feasible.
2. Several design options are attractive, depending on degree of compromise with military flexibility and commercial costs
   - Quick-change floor and mobile loader
   - Dedicated commercial freighter (selective loading)
3. Technology development is necessary for market penetration; minimum weight design options.
   - Graphite-epoxy primary structure
4. Military life cycle cost can be reduced 50% by using an IAV with design options.
5. Commercial cost increases can range from near-zero, if the dedicated commercial freighter or convertible is used, to 7% or approximately $2 billion over 20 years for the best design option.
6. Convertible passenger airplane with CRAF provisions appears to be an attractive design option, depending on pricing philosophy. A passenger module has good military utility but high commercial cost.
7. Drivethrough options are costly and only marginally beneficial.
8. Low number of design option units significantly influence procurement costs.
9. The most beneficial trend appears to be as little change as possible to the commercial design.

Figure 8.1 Conclusions

- Technology demonstrator is still required. USAF and NASA should form a joint program.
- Design option conversion mockups should be initiated to confirm conversion times, operational considerations, and loadability.
- Mobile ramp development and demonstration should be initiated.
- Detailed design studies should be initiated to optimize and validate the quick-change floor concept
- Convertible kneeling landing gear should be validated by design and test.

Figure 8.2 Recommendations

9.0 REFERENCES

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9.1 Intertheater Airlift Vehicle (IAV) - Statement of Need, Military Airlift Command (MAC).

APPENDIX A

COST ANALYSIS COST ESTIMATING (CACE) MODEL

The input data list to the CACE model is given in Figure A-1.

The CACE program results are shown on Figures A-2 and A-3, and represent the final USAF operating and support cost data for the dedicated military derivative aircraft in this Design Options Study

MODEL CODE	DESCRIPTION	FACTOR
000	Unit Equipment (PAA)	18
005	Utilization Rate, FH/PAA/YR	1000
010	Crew Ratio (CR)	2.5
015	Primary Program Element - Officiers	112
020	Primary Program Element - Airmen	784
025	Primary Program Element - -Civilians	72
030	Base Operations/Real Property Maintenance (BOS/RPM) - Officiers	5
035	Base Operations/Real Property Maintenance (BOS/RPM) -Airmen	87
040	Base Operations/Real Property Maintenance (BOS/RPM) - Civilians	98
045	Medical Dispensary - Officiers	3
050	Medical Dispensary - Airmen	10
055	Medical Dispensary - Civilians	3
060	Aircrew - Rated Officier, Pilots	90
065	Aircrew - Rated Officier Other	9
075	Base Maintenance - Airmen	666
085	Pay & Allowences - Officiers	$22,674
090	Pay & Allowences - Airmen	$ 9,833
100	Pay & Allowences - Civilians	$15 888
105	Permanent Change of Station - Officiers	$ 834
110	Permanent Change of Station - Airmen	$ 378
115	Medical - Officier Support	$ 644
120	Medical - Airmen Support	$ 567
125	BOS/RPM (incl. dispensary) -MAC	$ 234
130	Vehicular Equipment ($/FH)	54
137	Munitions Training	0
140	Fuel Aviation ($/FH)	$ 600
145	Base Level Aircraft Maintenance ($/FH)	$ 234
155	Depot Maintenance ($/UE)	$265,272.
160	Depot Maintenance ($/FH)	$ 671

MODEL CODE	DESCRIPTION	FACTOR
165	Replinishment Spares ($/FH)	$ 311
170	Flyaway Cost (FAC) (An approximation)	$ 50M
175	Modification Class IV, and Spares	.004494
180	SE (incl spares), Common	$13,190
185	UPT - Training	$125,174.
190	Aircrew Officier Training (excluding UPT)	$41,768
192	Nonrated Officier MY/Squadron	30
195	Nonrated Officier Training	$ 4,462
200	Airman Naintenance Function, Training	$ 5,826
205	Airman, Other, Training	$ 3,912
210	Acquisition Officier	$39,520
215	Acquisition - Airman	$ 3,453
225	PPE OMY and BOS/RPM OMY (incl Med. Off.)	120
230	PPE AMY and BOS/RPM AMY (incl. Med. Amn.)	880
235	PPE MMY and BOS/RPM MMY (incl. Med. Civ.)	144
250	Pilot Turnover Rate, Officier	.063
255	Other Aircrew Turnover Rate Officier	.059
260	Nonaircrew Turnover Rate Officier	.094
265	Airman Turnover Rate	.134
	Aircrew Airman	90
	Maintenance Man - Hrs/Fly Hour	25.6
	Productivity/Man-Mo	65.2
	Maintenance Supervision Factor	1.10
	SE Maintenance Factor	1.10
	Year of Dollars	FY 1978
	Ratio Wartime/Peacetime Manning (Surge Rate)	1,378

Total Base Maintenance Men / SQD = 686

$$= \frac{\text{MMH/FH} \times \text{PAA/SQD} \times \text{FH/PAA/YR} \times \text{Surge Ratio} \times \text{Sup. Fac.} \times \text{SE Main. Fac}}{\text{Productivity/Man-Mo} \times 12}$$

Figure A - 1 CACE Input Listing, Design Options Study

```
TASC06 NSAC-8
STORAGE = 00500K
CMS REL 5 01/10/80 U022
MAIL WAITING.

1.       NSAC 8 MODEL -- DESIGN OPTIONS
C.1 2
CE.1 1978 1978
PB.1 1000 85.2 PB.9 1.668 1.0
PC.3 1 0 PC.9 1 3
PM.4 .166 .016 .0303 .5394 .4303 .1875 .625 .1875 .0196 .8855
.0949 2 2 PM.18 0 20 0 7 8 1
PR.2 2.5 0 22674 9833 15888 834 378 644 567 54 PR.13 .004494 PR.15 234
PR.23 125174 41768 4462 5826 2912 39520 3453 .063 .059 .094 .134
PA.2 50000000
PB.7 18
PB.8 25.6
PR.12 311
PR.16 600
PR.19 265272
PR.20 671
PR.14 13190
PR.17 234
```

CASE NO 1 - 1 NSAC 8 MODEL -- DESIGN OPTIONS

MANPOWER DISTRIBUTION (CACE)
HEADCOUNT

	OFFICERS	AIRMEN	CIVILIANS	TOTAL
PRIMARY PROGRAM ELEMENTS (PPE)				
MAINTENANCE	15	666	71	752
CREWS	90	90	0	180
WEAPON SYSTEM SECURITY	0	20	0	20
SQUADRON OVERHEAD STAFF	7	8	1	16
WING BASE STAFF	0	0	0	0
MUNITIONS MAINTENANCE	0	0	0	0
ADDITIVES	0	0	0	0
TOTAL PPE	112	784	72	968
BASE OPERATING SUPPORT (BOS)	5	87	69	161
MEDICAL SUPPORT (MED)	3	10	3	16
SUB-TOTAL (PPE+BOS+MED)	120	880	144	1144
OTHER SUPPORT				
REC/TECH TRAINING	0	0	0	0
UPT/UNT	0	0	0	0
TOTAL OTHER SUPPORT	0	0	0	0
OVERALL TOTAL	120	880	144	1144

MARCH 5, 1980
TASC06 TOTAL SYSTEMS COST MODEL
SYSTEMS COST ANALYSIS ORGN (2-9231)

Figure A-2 Manpower Distribution (CACE), Headcount

CASE NO. 1 - 1 USAC 6 MODEL -- DESIGN OPTIONS

PLANNED ANNUAL SQUADRON COST (CACE) - 1978 DOLLARS IN MILLIONS

I. RECUR. INVESTMENT + MISC. LOGISTICS		41.799
SE, COMMON (REPL) + SPARES	0.237	
FUEL, AVIATION	10.600	
MAINTENANCE, BASE (MATERIAL ONLY)	4.212	
MAINTENANCE, DEPOT (LABOR + MATERIAL)	16.253	
MODIFICATION, CLASS IV + SPARES	4.045	
MUNITIONS, TRAINING	0.	
REPLENISHMENT SPARES	5.598	
VEHICULAR EQUIPMENT	0.054	
II. PAY + ALLOWANCES		13.661
MILITARY, PPE + BOS/RPM + MED	11.366	
CIVILIAN, PPE + BOS/RPM + MED	2.295	
III. BOS/RPM, NONPAY SUPPORT OF PRIMARY MISSION		0.268
PPE MAN-YEARS	0.226	
BOS/RPM MAN-YEARS	0.041	
IV. MEDICAL (MFP VIII) SUPPORT OF MISSION		0.576
OFFICERS, PPE + BOS/RPM	0.077	
AIRMEN, PPE + BOS/RPM	0.499	
V. PERSONNEL SUPPORT		0.432
PCS - OFFICERS	0.100	
PCS - AIRMEN	0.333	
VI. 'PIPELINE' SUPPORT		2.067
ACQUISITION - OFFICERS (PLT+NAV+NR)	0.334	
ACQUISITION - AIRMEN	0.407	
AIRCREW TRAINING - PILOTS (UPT)	0.710	
AIRCREW TRAINING - OTHER RATED	0.	
OFFICERS - NONRATED	0.012	
AIRMEN - AIRCRAFT MAINTENANCE	0.520	
AIRMEN - ALL OTHER	0.084	
VII. TOTAL ANNUAL COST ESTIMATE		58.803

MARCH 5, 1980
TASC06 TOTAL SYSTEM COST MODEL
SYSTEM COST ANALYSIS ORGN (2-9231)

Figure A-3 Planned Annual Squadron Cost (CACE) - 1978 Dollars in Millions